E-AMBULANCE: A REAL-TIME INTEGRATION PLATFORM FOR HETEROGENEOUS MEDICAL TELEMETRY SYSTEM OF SMART AMBULANCES

BY

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عمادة الدراسات العليا
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To Abdul Rahman and Fatima, my parents and my foundation.
To Manal, Manar, Maram, my lovely sisters.
To Hala, my Love.
Words cannot express how much I love you all.

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THESIS ABSTRACT

NAME:	Manaf Abdul Rahman Bin-Yahya
TITLE OF STUDY:	E-AMBULANCE: A Real-Time Integration Platform for Heterogeneous Medical Telemetry System of Smart Ambulances
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There are a vast number of researches in sensor networks, medical devices, wireless communication, middleware software and software applications that help advance improvements in the healthcare systems. Health monitoring systems deliver health status reports to actors such as people under monitoring, practitioners and coaches for several purposes. In this research, we propose E-Ambulance framework, which is a smart ambulance system model that provides health monitoring of patients for remote medical professionals. As well as provide an automatic responses of suggestions and warnings to paramedic staff inside an ambulance. Sensor networks record and deliver health status information to other elements of system. Due to the availability of information from sensors networks, an auto *response can take place by alarms supervised by Decision Maker unit. Remote decisions can be made in a medical center after receiving inputs generated inside an ambulance. Building a distributed real time system can handle all aspects of time critical systems and hide heterogeneity between elements and different types of data. Data Distribution Service (DDS) standard is used to build the proposed model. Several experiments are performed over DDS middleware to validate the efficiency, scalability, and availability of the E-Ambulance system in terms of latency, success ratio, and throughput. Moreover, different QoS policies parameters of DDS domain are regulated to have an efficient QoS policies profile. Furthermore, the data must be transmitted to remote destination such as another ambulance or a medical center. Therefore, the success of providing healthcare services depends on robust data delivery. Different technologies can be used by the gateway of ambulance network such as IEEE 802.11, IEEE 802.16, 3G and 4G. In this research work, we evaluate IEEE 802.11p short range communication over Makkah city scenario using NCTUns simulator environment. Our simulation results show that vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication models can be used to facilitate ambulances remote monitoring system.*

ملخص الرسالة

الاسم الكامل: مناف عبدالرحمن علوي بن يحيى

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التخصص: هندسة الحاسب الآلي

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هناك عدد كبير من الأبحاث في شبكات الاستشعار، والأجهزة الطبية، والشبكات اللاسلكية، والبرمجيات الوسيطة والتطبيقات البرمجية التي تدفع بالتطوير في أنظمة الرعاية الصحية. نظم المراقبة الصحية عن بعد تقوم بتقديم تقارير الحالة الصحية للمريض للاشخاص المهتمين مثل الشخص نفسه والأطباء والمدربين لأغراض مختلفة. في هذا البحث، نقترح نظام E-Ambulance (سيارة الإسعاف الإلكترونية)، وهو نموذج لنظام سيارات الإسعاف الذكية التي توفر المراقبة الصحية عن بعد للمرضى داخل سيارة الإسعاف للمختصين الطبيين. وكذلك توفر الاستجابات التلقائية لحالة المريض مثل الاقتراحات والتحذيرات لطاقم التمريض داخل سيارة الإسعاف. شبكة الاستشعارالطبية المرتبطة بالمريض تقوم بتسجيل و تزويد معلومات الحالة الصحية للوحدات الأخرى من النظام. ونظرا لتوافر المعلومات الصحية من شبكات وأجهزة الاستشعار الطبية، يمكن للاستجابات التلقائية أن تحدث عن طريق وحدة الإنذارات التي تشرف عليها وحدة صنع القرار. يمكن أن تكون هناك قرارات عن بعد من المركز الطبي المراقب بعد تلقيه الحالة الصحية للمريض داخل سيارة الإسعاف. وقد قمنا باستخدام معيار خدمة توزيع البيانات (DDS) لبناء هذا النموذج المقترح حيث انه يعتمد على الوقت الحقيقي و يستطيع التعامل مع جميع المتطلبات الحرجة للوقت وإخفاء عدم التجانس بين العناصر المكونة والأنواع المختلفة من البيانات. وقد قمنا بإجراء العديد من التجارب على البرمجية الوسيطة DDS للتحقق من حيث الكفاءة، وقابلية التوسع، وتوفر البيانات لنظام سيارة الإسعاف الإلكترونية عن طريق حساب مدة تاخير وصول البيانات، ونسبة النجاح، والإنتاجية. وعلاوة على ذلك، اختبرنا عدة عوامل متغيرة لسياسات جودة الخدمة للـ DDS لايجاد ملف تعريف سياسات جودة الخدمة الذي يعمل بكفاءة. وعلاوة على ذلك، يجب أن تنتقل البيانات من داخل سيارة الاسعاف إلى جهة بعيدة مثل سيارة إسعاف أخرى أو مركز طبي. ولذلك، فإن النجاح في تقديم خدمات الرعاية الصحية عن بعد يعتمد على كفائة نقل هذه البيانات. هناك تقنيات مختلفة يمكن استخدامها من قبل نظام سيارة الاسعاف الالكترونية مثل الشبكات اللاسلكية (واي فاي – واي ماكس) او الشبكات الخليوية (الجيل الثالث – الجيل الرابع). في هذا العمل البحثي، قمنا بتقييم الشبكة الاتصالات اللاسلكية قصيرة المدى الخاصة بالسيارات المعروفة ب (IEEE 802.11p) على سيناريو خاص بمدينة مكة المكرمة باستخدام بيئة المحاكاة NCTUns. وأشارت نتائج المحاكاة بأن شبكات اتصالات سيارة إلى سيارة (V2V) وسيارة إلى اجهزة البنية التحتية (V2I) يمكن أن تستخدم لتسهيل نظام المراقبة الصحية عن بعد داخل سيارات الاسعاف.

CHAPTER 1

INTRODUCTION

Smart healthcare systems becomes a hot area for all of medical, computer, and networking fields researchers. They are trying to advance the existing healthcare services with the improvement of sensor networks, medical devices, wireless communication, middleware software and end software applications. Health status monitoring indoor and outdoor attracts many researchers in order to have early detection of diseases, provide emergency help, and reducing the medical costs.

In health status monitoring systems, periodic physiological status of people must be collected using sensors and delivered to medical staff through communication system. Beside this periodic data, these systems must provide emergency status reporting under critical situations. Different vital signs can be gathered depends in the purpose of healthcare system and what it is concern. Due to properties of wireless sensor networks, they are used widely in health monitoring systems. Alemdar et at. [2] studied exhaustively most of existing healthcare systems that based on wireless sensor networks and provide a discussion of advantages, issues, and design consideration of implementing healthcare system.

Many of patients with critical condition lost their life inside ambulance because they need urgent aid to survive. Medical professionals who have high chance to save their life are serving in medical centers. So essential treatment will take place in these medical centers and just first aid can be provided in ambulance. Therefore, in this paper, we will propose an E-Ambulance system which can provide remote health monitoring and auto responses which can be handled in ambulance to save patient(s) life.

In normal situations, the ambulance is summoned to carry patients to medical center (such as hospital). Many issues can occur regarding to patients condition and the need to deliver them to a medical center. Two categories of these issues defined here; (1) Monitoring patients status and provide urgent responses. (2) Reaching nearest suitable medical center as soon as possible. These two issues are considering as distributed real-time system. This problem needs such a model design which can handle all aspects of time critical distributed systems. To accomplish that we use Data Distribution Service (DDS) standard [14] to build our real-time system.

1.1 Research Motivation

Monitoring of health status for patients inside ambulance is accomplished by wearable biosensors which attached to their bodies as shown in Figure 1.1. Regular monitoring of different vital signs is needed by these sensor devices. Wireless sensors can augment or replace expensive and cumbersome wired telemetry devices for pre-hospital and ambulatory emergency care when real-time health monitoring of patients is necessary [15, 16]. On the other hand, wired biosensors can be used inside ambulance and connected to WSNs through control devices. Connection problem for wired biosensors will occur due to number of wires and limited area of patient compartment. Therefore, there are partially wired devices used in health monitoring; multiple body sensors connect with each other using wires and can transmit data through wireless channel [17].

Variety of sensor platforms which involve on health monitoring system led to the need of a solution handles this heterogeneity. Any failures in delivering certain information about patient health status might cause catastrophic consequences such as patients lose their life. Thus, it required fast response time for all actions can be handled. A real-time platform is required to collect data from sensors and deliver it to destination.

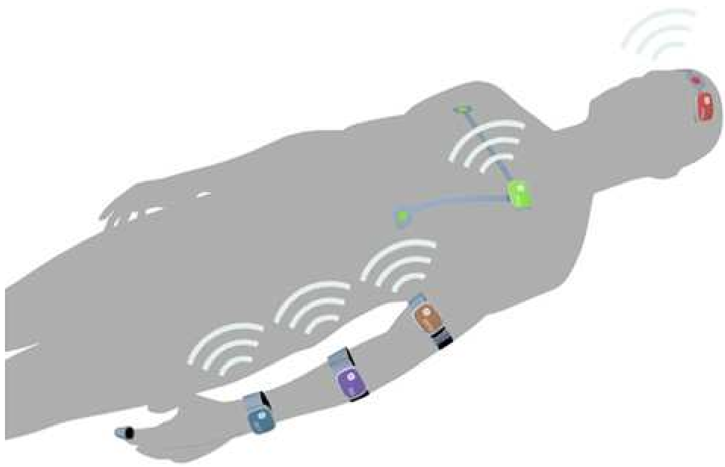

Figure 1.1: Heterogeneous medical sensors platforms used in healthcare system.

The data must be transmitted to remote monitoring destination such as another ambulance or a medical center. Therefore, the success of providing healthcare services depends on robust data delivery. Different technologies can be used by the gateway of ambulance network such as Wi-Fi, WiMAX, and 3G [18]. In this platform, cellular/Wi-Fi devices can be used for both short and long range communication. Vehicle to vehicle (V2V communication can provide data exchange platform and facilitate remote monitoring system development. Wireless connectivity, including wireless LAN localization can be dedicated for this type of vehicular networks.

1.2 Thesis Objectives

The main objective of our research work is to propose telemedicine platform for ambulances that provide real time remote health monitoring of patient inside ambulance to medical professionals. To gain this objective, our work is divided into number of sub-objectives described below:

- To propose smart ambulance system for critical health monitoring of patients inside ambulances. Also, to provide description of each system element and its aspects. (chapter 4)

- To build smart ambulance platform over real time middleware of DDS standard. Where, data distribution service standard handles real time and heterogeneity issues. (chapter 5)

- To define how system elements interact with each other and their roles in

DDS environment. Furthermore, to define QoS policies that must be used in our proposed system. (chapter 5)

- To find appropriate QoS policies combinations (profiles) for such a real-time system by evaluating system performance under these profiles. (chapter 6)

- To provide performance measures latency, success ratio, and throughput of Body Area Network inside ambulance over Wi-Fi to examine different QoS profiles. (chapter 6)

- To use V2V and V2I communication models to connect between source ambulance and remote destination (such as another ambulances or medical centers). In that case, to implement this model in a test scenario of Makkah city. (chapter 7)

- To evaluate the impact of different aspects that may raise or degrade performance of vehicular network model for remote delivering of health information over several aspects such as the use of infrastructure stations, vehicle density, vehicle speed and routing protocol. (chapter 7)

1.3 Thesis Organization

The rest of the thesis is organized as follows. In chapter 2, we provide a background needed to cover this research. Chapter 3 gives a review of previous related works. In chapter 4, we describe E-Ambulance platform model and its components. In chapter 5, we discuss how DDS is a significant part in our solution. Then we provide the details of experimental works and results of implementing our platform over DDS in chapter 6. Chapter 7 gives description of simulating vehicular network model of inter communications and the obtained results. Finally, we conclude and suggest future work in chapter 8.

CHAPTER 2

BACKGROUND

2.1 E-Healthcare Systems

Google search terms histogram as measured by Google Trends [1] of eHealth as field of study, Telemedicine and Telehealth as topic search terms during last 8 years is shown in figure 2.1. interestingly, these three terms raise the attention of people around the world from different aspects. Most likely, this trends will keep gaining interests for the coming decades.

Many aspects of human life have changed such as healthcare, entertainment, industry and emergency management because of the growth in wireless sensor network. Modern healthcare systems use wireless sensor network technologies to improve its services especially for chronically ill and elderly monitoring and tracking. Remote health monitoring and tracking is one of auspicious achievement of pervasive healthcare systems. Practitioners will be able to identify risky conditions easily and then provide urgent response with remote monitoring of at risk patients without preventing them to live freely without many restrictions.

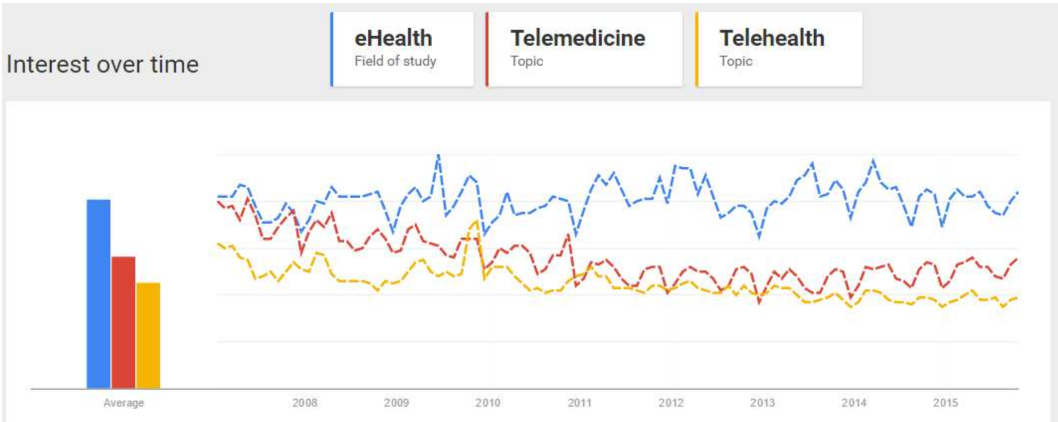

Figure 2.1: Google search terms histogram [1].

As mentioned in [2] there are four actors in most of healthcare systems:

- Children
- Elderly and chronically ill
- Caregivers
- Healthcare professionals

2.1.1 Health Monitoring System

Health monitoring is one of these promising e-healthcare applications. With benefit of biosensors and environmental sensors, constant monitoring will lead to the early detection of disease and emergency situations for patients leading to find appropriate responses according their cases. Most of health monitoring systems consists of different subsystems shown in figure 2.2 which interact with the main actors categories to provide these medical services [2]:

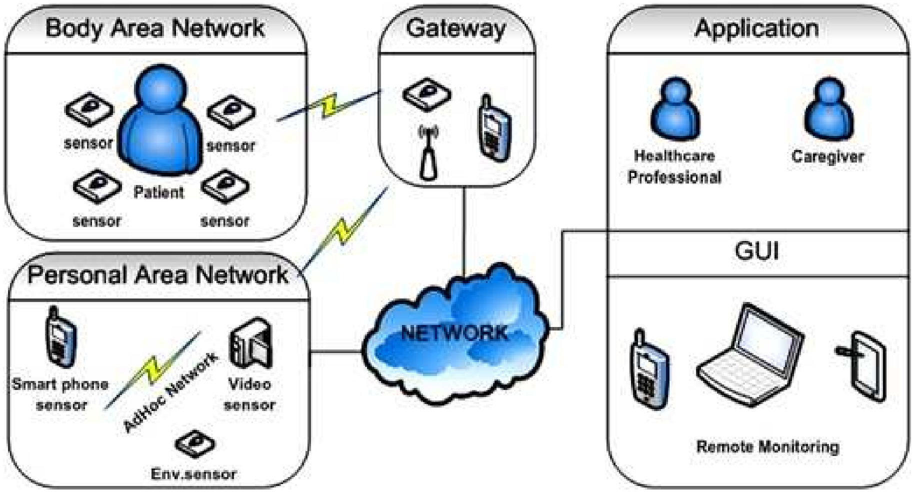

Figure 2.2: Overview of simple healthcare application scenario [2].

Body Area Network (BAN) Subsystem

Terminology of Body Sensor Network becomes more familiar of WSNs that is used for healthcare applications due to wide usage [19]. BAN consists of biosensors and tags that patients wear on their bodies such as ECG sensors. These types of sensors can provide complete health status information of person who carries it.

Personal Area Network (PAN) Subsystem

PAN provide contextual information of patients using mobile devices which own by patients and environmental sensors located nearby (such as RFID, Video cameras, Sound, Pressure sensor, Temperature sensor, Humidity sensor) [2]. Localization and tracking services can be provided using this subsystem. Moreover, any device can be included in this network if it has capability of connecting with other PAN devices.

Gateway and Wide Area Networks

The gateway is responsible to collect data comes from BAN and PAN sensors and send it to the remote destination through WANs. The connection between patient's subsystems and practitioner's subsystem can be provided through different type of technologies such as 3G, WiMax and WiFi [2]. Therefore, the function of WANs is to relay health status data to one destination or more depends on the healthcare services. (Technology independent)

End-user healthcare monitoring application

This subsystem collects and interprets data delivered from remote sources and triggers appropriate responses [20]. The end-user application consists of two main parts:

- Processing part:

Analyze data using different algorithms and machine learning techniques to detect any emergency condition of patient [21].

- GUI part:

Provide constant health status information of patients under monitoring and alerting services for any important conditions.

2.1.2 Prototypes Categories

There are many healthcare applications that use wireless sensor network. In this part, we will discuss four main prototypes:

Fall and movement detection

Accidental falls of people is the major cause of death especially for elderly. Therefore, there is considerable effort by researchers on fall and movement detection through analyzing human poses and gaits. So, this type of prototypes falls under the name of activity classification. Prototypes proposed in [22] and [3] are examples of fall and movement detection category.

Figure 2.3: HipGuard: a garment integrated measurement system [3].

Location tracking

In this type of prototypes, healthcare system works on indoor and outdoor scenarios together. Most of indoor applications track the target by using personal area network or by wearing certain type of sensors that send data to access points to locate the target. GPS sensors are the best solution for outdoor applications due to its wide usage and availability. By detecting people locations, assisting or alerting conditions might be triggered. Prototypes proposed in [10, 4, 23] are examples of location tracking category.

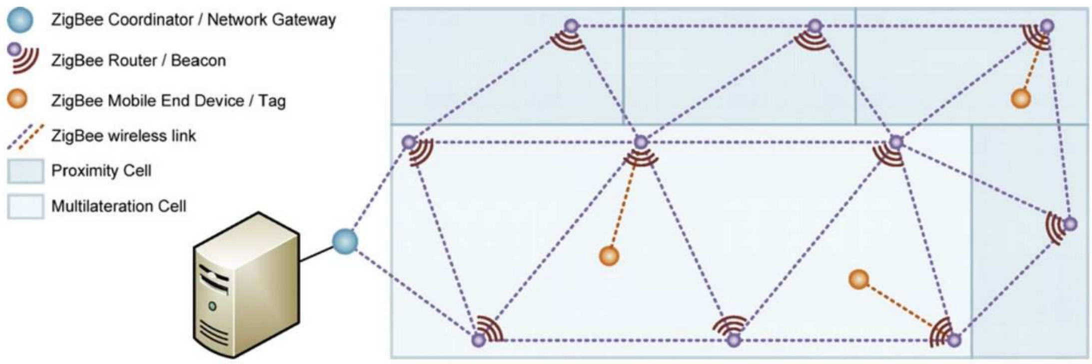

Figure 2.4: System architecture for providing location based services for elderly and disabled people proposed in [4].

Medication intake monitoring

Medication intake monitoring is needed because chronically ill and elderly tend to medication non-compliance. Prototypes proposed in [24, 5] are examples of medication intake monitoring category.

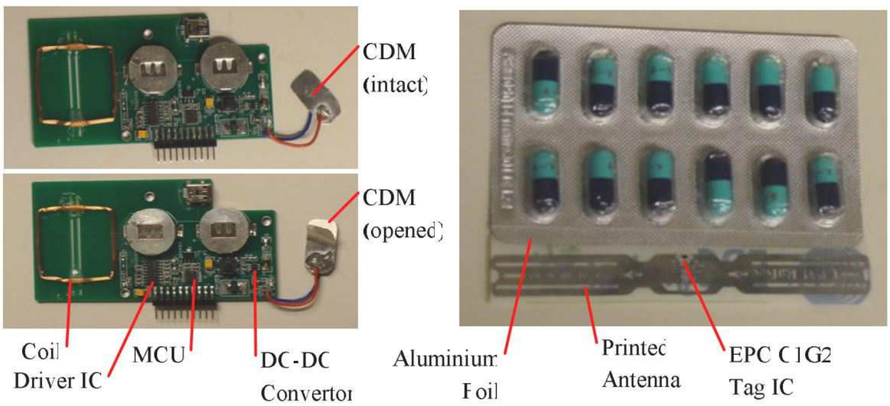

Figure 2.5: A prototype of iPackage for medication intake monitoring system [5].

Health status monitoring

Health status monitoring is the most studied category of e-healthcare systems which concentrate in witnessing health status of patients to deliver reports to actors such as people under monitoring, doctors, and coaches for various reasons. In this type of prototypes, most of data are gathered using wearable biosensors and Body area networks and then transferred to remote destination to provide analyzing and alerting services. Heart rate, pulse oximetry, body temperature, electrocardiography and blood pressure are the commonly used vital signs.

2.2 Real-Time Systems and Middlewares

2.2.1 Real-Time Systems

Real-time systems consist of group of nodes exchange data through a real-time connection network in distributed environment. Where, the correctness of system operation does not only depend on logical aspects but also depends upon the time in which it is delivered. According to operation deadline constraints, different types of real-time system are classified:

Hard Real-Time Systems

In this category of systems, the availability of data after the deadline constraint cause a system failure. Therefore, time constraints must meet always by system actors. Some health applications such as pacemakers and critical emergency application are examples of hard real-time systems.

Firm real-time system

In this category of systems, rare failures of completing operation in deadline constraint. However, many failures could reduce the performance and quality of service of the system. Short term health monitoring systems is an example of this type of systems.

Soft real-time system

In this category of systems, failures can only degrade system performance and quality of service but it does not cause system failure. The data does not loss its whole value when it delivers after time constraint but its value degrades as time passes after deadline constraint. Long term health monitoring systems and video streaming are examples of this kind of systems.

2.2.2 Middleware

Middleware solution arises to ease the system resources management. Therefore, middleware enhance system application development by linking low layers of operating systems and high layer applications. Consequently, middleware capable to hide the heterogeneity and complexity of the low level software and hardware. Furthermore, Middleware is used in sensors systems and support work phases of these systems, such as data execution, maintenance and development. In sensors system, particular feature should be provided by middleware due to sensors properties such as heterogeneity, scalability, ability to save power, and mobility. Additionally, ease of use, managing resources, security and quality of service (QoS) characteristics must be delivered by feasible middleware solution.

More importantly, each node details of the underlying operating system, protocols stack, and hardware architecture are hid by the middleware layer to simplify the development of sensors distributed environment. In that case, upper layers can communicate and exchange data with other nodes across a network without the need of knowing delivery management issues. Accordingly, platform-independent Application Programming Interface (API) is required to achieve this goal.

Apart from this, real-time system requirements must be supported for some applications. More simply, sensors network environments are not constant and changing with the time axis. This alteration includes altering in time and space. Therefore, middleware solutions must be support real-time requirements to adapt to the alterations of such environments like sensors network. A consequence of the gap between different hardware platforms and technologies, a cross platform communication is required to bridge this gap by providing some interfacing and linking mechanisms.

2.2.3 Data Distribution Service (DDS)

Data Distribution Service (DDS) [14] is a standard base Application Programming Interface (API) offers publish-subscribe model of communication to hide the underlying complicated network layers by providing a software layer over networking stack. Communication aspects and network management are handled by DDS to achieve reliable and transparent data flow. However, no application interference will take place.

Data Distribution Service model have two main actors (in UML terminology); Publishers and Subscriber. Publishers are simply which generate date (Topic) and publish it in the domain. The data will deliver to certain nodes in the domain whenever it changes; these nodes called Subscribers; as shown in Figure 2.6. Any node in the domain can be Publishers, Subscriber, or both at the same time of many different Topics [25]. Each topic corresponds to a single data instance. A DataWriter associated with a topic can write to the instance corresponding to that topic. It should be noted, multiple DataWriters may write to the same instance. A DataReader specifies the topic (instance) it wants to receive updates from. Again, multiple DataReaders can listen to the same instance.

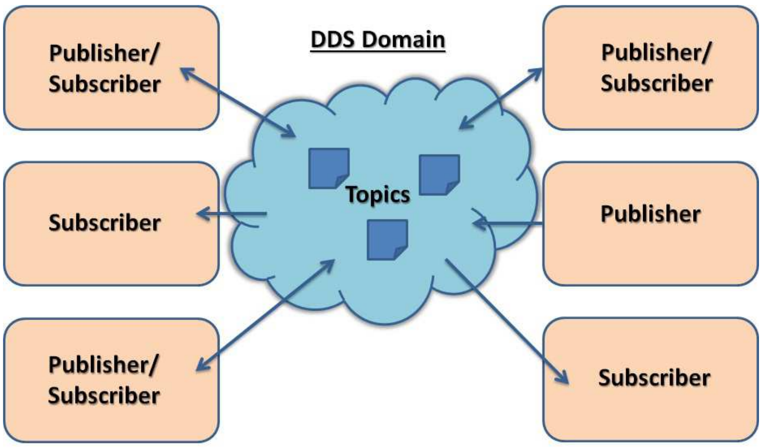

Figure 2.6: Data Distribution Service model.

Quality of Services (QoS) Policies

Different Quality of Services (QoS) policies are supported to give designers spacious options to adjust their applications for efficient resource usage and performance [26]. Reliability, History, Durability Partition Deadline Time-Based Filter Lifespan Presentation are QoS policies integrated with DDS standard. An applied example, In GPS system, Publisher is the Global Positioning System (GPS sensor which send location information periodically to subscribers. The system can estimate speed and direction if sensor goes down for period of time without notifying end users. Therefore, Through DDS; communication between elements of heterogeneous system become easily. In this section, a description of main QoS policies is provided.

Reliability QoS policy

Reliability QoS policy Controls the reliability between the publishers DataWriter and the subscribers DataReader. When the reliability QoS is set to RELIABLE, the system will attempt to repair samples that were not successfully received. Therefore, reliability is also controlled in conjunction with other QoS policies, such as History and ResourceLimits, to determine which data remains relevant and therefore eligible for repair. Reliability BEST EFFORT value means that the system will not use any resources to guarantee that the data sent by a DataWriter is received by a DataReader. Best effort delivery is the fastest, most efficient, and least resource-intensive (CPU and network bandwidth) method of getting the newest/latest value for a topic from DataWriters to DataReaders but with the cost of no guarantee to receive data.

History QoS policy

History QoS policy Controls how the system manages frames payload sent by a publishers DataWriter or received by a subscribers DataReader. It helps tune the reliability between publishers and subscribers.

Durability QoS policy

Durability QoS policy controls whether or not new subscribers get data which was published by publishers DataWriters earlier, to increase system tolerance to failure conditions.

Partition QoS policy

Partition QoS policy control which DataReaders can be communicated with certain DataWriter. Normally, DataWriters are connected to DataReaders of the same Topic. However, by using the partition QoS policy, additional criteria can be used to decide if a DataWriters data is allowed to be sent to a DataReader of the same topic. One or more strings can be added to the DataWriters publisher or DataReaders subscriber parent topic. In such a case the DataWriter is only connected to a DataReader for the same topic only if their publisher and subscriber have a common partition.

Deadline QoS policy

Deadline QoS policy can provide synchronization data flow between data sources and destinations at a consistent rate. This parameter identifies how long time a Subscriber should wait for data, and consistently, the minimum rate at which a publisher issues a new data. Publisher indicates that a new value of data is delivered at least once every deadline period and Subscriber expects a new data at least once every deadline period. Deadline QoS parameter is also used as an indicator of network performance degradation.

Time-Based Filter QoS policy

Time-Based Filter QoS policy controls the rate of data samples that should be delivered to a DataReader within the permitted deadline. Data samples for a DataReader can be filtered out using the Time-Based Filter QoS by setting the minimum separation time. Once a data sample for an instance has been received, the middleware will accept but drop any new data samples for the same instance that arrives within the time specified by minimum separation. Minimum separation time should be less than the deadline time. Simply, time based filter QoS allows receiving the data samples within a period of time (deadline) but after the time specified by minimum separation.

Lifespan QoS policy

Lifespan QoS policy specifies how long the system should consider data sent by a publisher to be valid. It is used to timestamp all data sent and received.

Presentation QoS policy

Presentation QoS policy controls the order of data received by DataReaders. Usually DataReaders will receive data in the order that they were sent by a DataWriter. In some conditions data might arrive out of order, for instance when using a reliable connection. In such conditions, data will be buffered until all previous samples arrive and presentation QoS will play a role in how to present those samples to the DataReader. Moreover, a set of data for the same topic sometimes is needed to be presented to the receiving DataReader only after all of the elements of the set have been received, but not before, or in a different order than what was received. Thus, presentation QoS policy allows the user to specify different scopes of presentation, within a topic, across instances of a topic, and across different topics of a publisher.

2.3 Smart Vehicles and Vehicle Area Networks (VANs)

The growth of smart vehicles concept pushes researches toward intelligent communications among vehicles and roadside infrastructures [27]. Most of attention is paid for safety application to assist drivers and create free accidents and collisions transportation environment [6, 18]. Smart vehicle is considered to be equipped by computer chip with sensors, network interfaces and GPS navigation equipment [27]. Faezipour et al. [6] provides an overview vision of VANs communications as shown in 2.7 and presents its research progress and issues. Using available communication standard, two or more vehicles in radio range can connect and talk with each other or try to share information with infrastructure. Therefore, each vehicle can identify position and movement of neighbour vehicles. Also, Information of road condition and offered services according to vehicle location can be provided by roadside infrastructure [28].

2.3.1 Wireless Communication Technologies used for VANs

Personal Area network standards are used for communications between on-board hands free system inside smart vehicle such as Bluetooth and ZigBee [29]. This in-vehicle communication called Intra VAN. In Inter VAN, smart vehicles send and receive data to/from another vehicles or roadside infrastructures. Smart vehicle

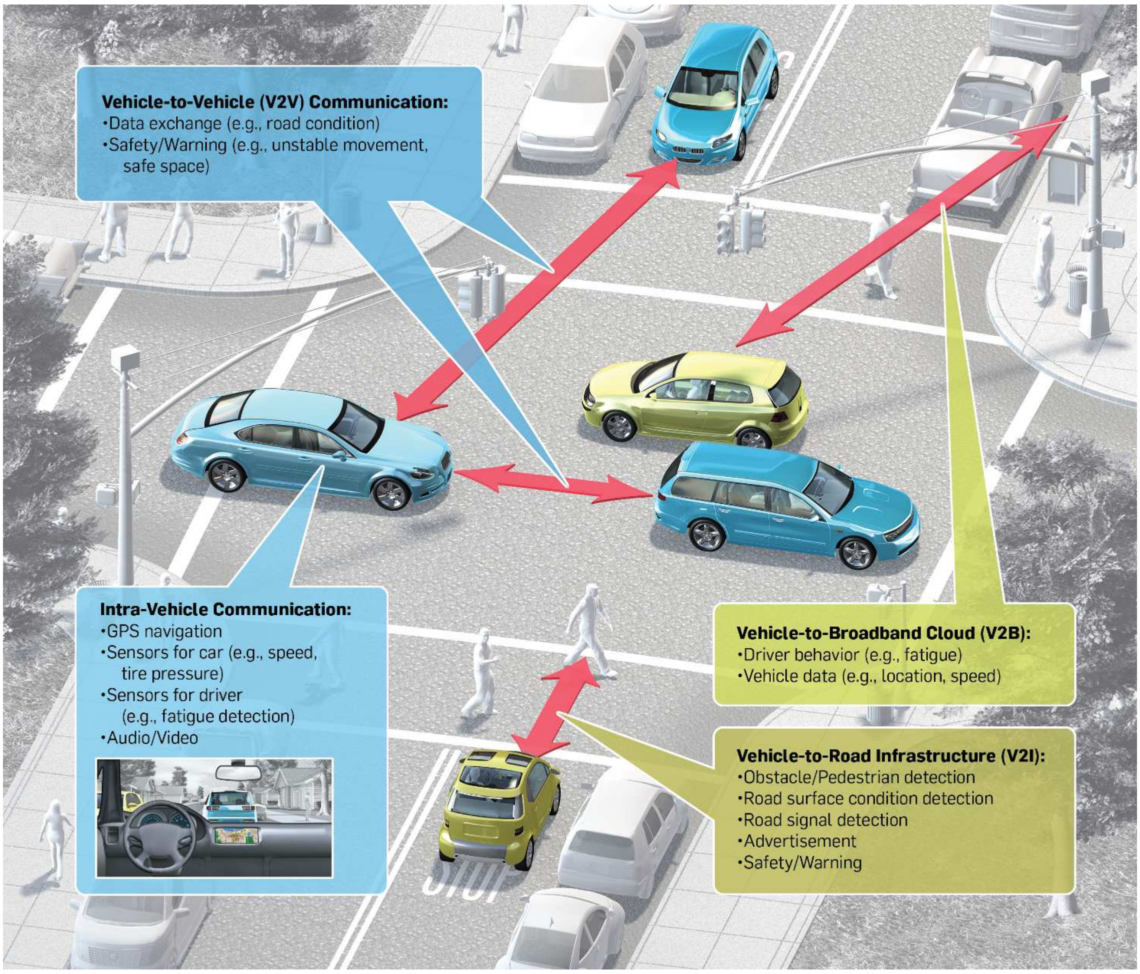

Figure 2.7: Overview Vision of Vehicular Area Networks [6].

might share information of its location and speed, road condition and warning messages to intelligent transportation system units [6]. This significant information will assist drivers and create safe driving environment.

2.3.2 V2V and V2I Communications

Wireless LAN communication of IEEE 802.11p and IEEE 802.16 (WiMAX) standards are used for this type of connectivity [29]. When a vehicle gets in radio communication range of other vehicle, they link with each other and join an ad hoc network called VANETs (vehicular ad hoc networks) [18]. These wireless LAN communication ranges are limit depend on interface that used. Therefore, multi-hop communication is required to allow any vehicle to send data over vehicles to reach the destination of messages [29]. Any smart vehicle may act like source, destination or intermediate nodes in VANETs. Several routing mechanisms are used in such high speed ad hoc network which can handle fast changes of topology such as flooding, position based, periodic beaconing and destination based routing algorithms [6, 18].

V2V communication take place between a vehicles with other vehicles directly. On the other hand, V2I communication is between vehicles and the infrastructure units which are fixed units beside the road called Road Side Unit (RSU). These RSUs can work as intermediate node between vehicles or as a gateway for vehicles to the outside world. Furthermore, the terminology of V2X refers to inter-vehicle communication where V2V communication combined with V2I communication in the same model.

VANETs are a significant element of intelligent transportation systems (ITS). Dedicated Short Range Communications (DSRC) is a major project of ITS specialized to standardize inter-communication of VANETs. Thus, DSRC refers to set of standards concern with V2V and V2I communication links that leads to use VANETs technology in real life world.

Wireless Access for Vehicular Environments (WAVE) refers to the specific WiFi protocol IEEE 802.11p which designed and implemented particularly for vehicle networks to support high data rate communication, dynamic environments, high mobility nodes and short connection links lifetime. WAVE standard consists of set of standards namely; 1609.2, 1609.3, 1609.4 and 802.11p. First three standards are higher administrative level implementation for protocols architecture of OSI layers. On the other hand, IEEE 802.11p/DSRC is responsible for managing Medium Access Control (MAC) layer and physical layer communication of VANETs.

IEEE 802.11p protocol achieves vehicular network requirement and support characteristics mentioned below:

- Long transmission range (approximately range between 1m up to 1000m).

- High speed nodes (up to 200km/h).

- Low latency.

- Multi-path connections environment.

- Quality of Service extensions (QoS).

- Message broadcasting (for vehicular-oriented and automotive applications such as safety).

2.3.3 Routing Protocol

Vehicular network is subset of ad hoc network where each vehicle represent a regular node. The main difference is in the mobility of those node where nodes in vehicular networks move faster than nodes in typical ad hoc networks. As a consequence of this difference, the obtained route lifetime is shorter in vehicular network. In addition, vehicle as an ad hoc node does not has power constraints and has higher computing capabilities. However, vehicular network as MANETs required multi-hop communication using intermediate nodes in order to increase the efficiency of delivering data. AODV [30], DSDV [31] and DSR [32] are well-known ad hoc network routing protocols. Accordingly, these routing protocols can be used in vehicular networks. AODV and DSR are reactive or on demand routing protocols which means protocol only active and obtain routes when there is data to send. On the other hand, DSDV is proactive or table driven protocol which means protocol discovers network topology and obtains routes to all other nodes periodically.

DSDV (Distance Sequenced Distance Vector)

DSDV is a table driven protocol as mentioned before. DSDV is distance vector routing protocol where each node create a table contains routes for all reachable nodes in term of next-hop and hops count. In DSDV protocol, every node broadcast updates for routing paths to build route table. Each route update has a tag (sequence number)to ensure loop free routes. Furthermore, if the sequence number of certain update is higher than others then this route update is feasible. While if there are two or more route update have the same sequence number, lower number of hop route is feasible. The sequence number is increased when a node detects that a route to a destination has broken. So the next time node advertises its routes, it will advertise the route to destination with an infinite hop count and a sequence number that is larger than before.

AODV (Ad hoc On Demand Distance Vector)

AODV algorithm enables dynamic, self-starting, multi-hop routing between participating mobile nodes wishing to establish and maintain an ad-hoc network. AODV allows mobile nodes to obtain routes quickly for new destinations, and does not require nodes to maintain routes to destinations that are not in active communication.

An AODV node maintains a routing table that holds information like: destination address, next hop address hop count, destination sequence and lifetime. In order to keep updated the routing table, the AODV protocol has two tasks; Route Discovery and Route Maintenance. The Route Discovery is used when it does not exist a route to a certain destination. The source send a broadcast message called route request contains the required destination address. A route reply can be generated by destination node or any intermediate node has the route.

DSR (Dynamic Source Routing)

DSR is a reactive protocol based on the source route approach. Source routing is a routing technique in which the sender of a packet determines the complete sequence of nodes through which to forward the packet. The sender explicitly lists this route in the packets header, identifying each forwarding hop by the address of the next node to which to transmit the packet on its way to the destination host.

When a host needs a route to another host, it dynamically determines one based on cached routing information and on the results of a route discovery protocol. Each mobile host participating in the ad-hoc network maintains a route cache in which it caches source routes that it has learned. If a route is found, the sender uses this route to transmit the packet. If no route is found, the sender may attempt to discover one using the route discovery protocol. While waiting for the route discovery to complete, the host may continue normal processing and may send and receive packets with other hosts. When route maintenance detects a problem with a route in use, route discovery may be used again to discover a new, correct route to the destination.

2.3.4 VANs Applications

Smart vehicle have a lot of benefits in real world. And here we mention some of these applications [29]:

Safety systems

Collision avoidance systems, unsafe driving profiling, intelligent air-bag deployment systems, communication between the vehicle and roadside objects.

Navigation and traffic information systems

A vehicle equipped with a telematics unit can direct a driver to a desired location, while providing real-time traffic information.

Voice recognition and wireless Internet connection

Drivers and their passengers can receive and send voice-activated e-mails while on the road.

Security systems

Vehicle anti-theft and stolen vehicle tracking services. On equipped vehicles provide tracking and remote door unlocking.

Diagnostics and maintenance services

Remote diagnostics and/or maintenance systems, vehicle and driver monitoring.

Table 2.1: Brief comparison between real experiments and simulation solution

Property	Real experiments	Simulation
Cost	Expensive	Cheap
Implementation	Difficult	Easier
Results scalability	Low	High
Modification flexibility	Hard	Flexible
Results utility	Low	High

2.4 VANs Simulation

Many issues appears when vehicle networks are evaluated in real experiments such as costs, time consumption, confidentiality of results, intensive labor and complex real environment. However, it is very important for simulation solution to handle realistic mobility model besides ad-hoc network routing. A brief comparison between real experiments and simulation solution is shown in table 2.1.

Again, VANETs are subsection of MANETs where each mobile node represent a vehicle with high speed moving through traffic model of mobility, roads, and traffic lights. However, VANETs have many distinctive characteristics that differs from MANETs where high speed nodes of VANETs is the main difference. A brief comparison among different types of as hoc networks such as MANET, Wireless Sensors Network (WSN), and VANET is shown in in table 2.2 and the main characteristics of VANETs are described below:

- The speed and density of nodes are very high. Therefore, network topology and connectivity are changing continuously with respect to time.

Table 2.2: Ad hoc networks types comparison

Property	MANET	WSN	VANET
Network size	Medium	Large	Large
Mobility	Random	Mostly static	High, Predictable
Energy limitations	High	Very high	Very low
Computation power	-	Very low	High
Memory capacity	-	Very low	High

- The network area is very wide because it can extend over cites. In addition, many high movement network members are included. For this reason, vehicular networks are large scale networks.

- The movement of vehicles is restricted to roadways thus the mobility of nodes tends to be predicted.

- Unlike other mobile networks, nodes in vehicular networks have unlimited transmission power and high computational capability powered by vehicle itself.

- Due to unavailability of transceiver elements in all vehicles and frequent changing of network topology and connectivity, the network could be highly fragmented. In other words, fragmentation occurs because of gabs between connected vehicles and produce isolated vehicle groups.

- Very short communication lifetime since a vehicle might be connected with fixed RSUs or another vehicles move in the same or opposite direction.

Consequently, VANETs simulation environment and requirements are essentially dissimilar to MANETs. In other words, VANETs characteristics and issues must be considered such as vehicles speed and mobility, road topology, traffic flow model, large scale area, high density, etc. In vehicular networks, nodes of VANETs are mobile vehicles and fixed RSUs. Whereas, network topology is varying continuously due to high movements of vehicles. Vehicles movement is usually limited by road topology. Theses nodes behaves as transceivers that is each node can send and receive data at the same time. In typical cases, network model and mobility model are required as simulation components. These two component might be separated in different simulators or combined in one simulator. In most of VANET simulation cases, network simulator and mobility generator are not integrated. There are many general MANET simulators can be used for VANET simulation as well as specific VANET simulators. We can classify VANET simulators into three categories; Network simulator, Mobility simulator, and Integrated simulators as shown in figure 2.8.

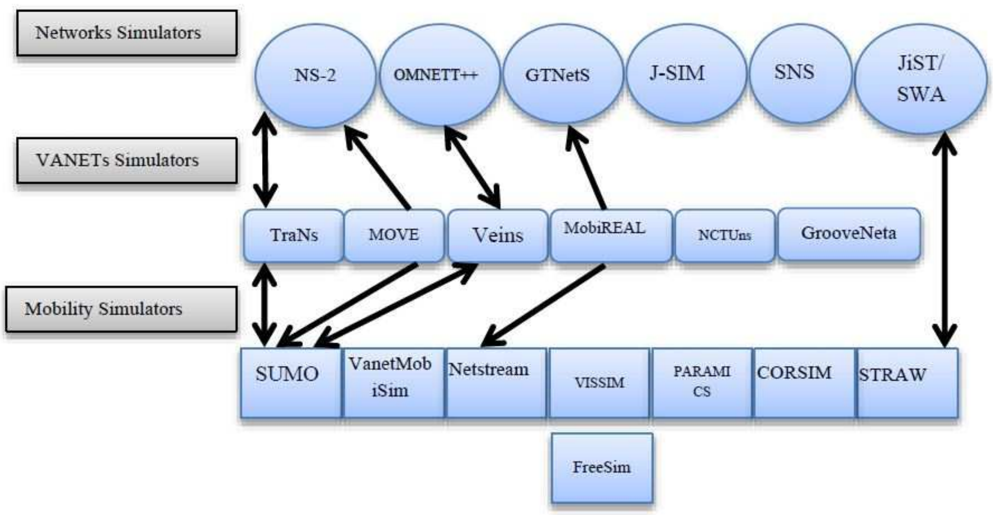

Figure 2.8: VANETs simulators categories [7].

In fact, Mobility generator is responsible to generate all traffic flow and vehicles movement traces which lately could be used as an input for network simulation to provide the mobility model. While, network simulator determine all data network aspects and components such as data transmission, nodes structure, communication channels, etc.

2.4.1 Mobility Simulators

Mobility simulators such as CORSIM [33], VISSIM [34], SUMO [35], VanetMobiSim [36], Citymob [37] and MOVE [38] are vehicular traffic generator of realistic mobility traces used in VANET simulation. The output of this simulator contain all information about mobility simulation model such as paths, movements, placement of lanes and traffic elements. Vehicular traffic features are very important to determine such as traffic signs, turning lanes and traffic lights combined with vehicles sets how a node will travel from starting point to end point in the real world. In fact, modelling vehicular nodes movement with a high degree of accuracy is much demanded to get accurate input for network simulation component.

2.4.2 Network Simulators

Network simulators are widely used to simulate data networks as an efficient, fast, ease of use and cheap solution. Researchers study behaviour of networks under several different condition using the network simulators by adjusting simulation parameters to generate results that meets with specific requirements. Different data networks scenarios could be simulated to test the existing technologies and protocols or to create and test the new or novel proposed technologies and protocols. In most cases, network simulators are used for examining the VANETs by evaluating the performance of network protocols for mobility of nodes and other required technique. Most currently used network simulators are developed for MANETs and hence require VANET extensions (such as using the vehicular mobility generators) before they can simulate vehicular networks. OMNET++ [39], NS-2 [40] and NS-3 [41] are examples of this type of simulators.

2.4.3 Integrated Simulator

As mentioned before, integrated simulators combine mobility generator and network simulator in integrated framework. GrooveNet [42], NCTUns [43], and TraNS [44] are an example of this type of simulators. However, these simulators must handle heavy mobility model simulation and large scale network modelling to generate high accurate outcomes.

2.4.4 VANETs Simulators Comparison

Several of commercial and free-license simulators exists in research field by the industry and internet community. Traffic or mobility simulators are dedicated to the studies of road networks, vehicle movement modelling, and drivers behaviour which is useful for transportation engineering field. Whereas, Network simulators are mostly used to study protocols and applications under various network conditions. To study certain systems such as intelligent transportation systems (ITS), a tightly integrated platform is required to run mobility and network simulation simultaneously. Nevertheless before simulating vehicular networks, most of network simulators needs a vehicular mobility generator extensions as shown in figure 2.8. Accordingly, integrated simulators are the optimal solution for many cases such as ITS applications. A lot of studies are published to provide comprehensive and comparative view of these tools to help researchers in vehicular field.

Features charts of widely used simulators (ns-2, OMNET++, ns-3 and NCTUns) are shown in figure 2.9. Most of simulators does not support IEEE.11p (WAVE) standard in their environment. As a result, researcher use other IEEE 802.11 standards for this purpose even though IEEE 802.11p is modified version of WiFi with vehicular features. While NCTUns is a vehicular simulator and has full support of IEEE 802.11(p) in its 6.0 version. Moreover, NCTUns supports different mobility and control models for vehicles movement, road and map construction, and road side infrastructure. Apart from this, Linux TCP/IP protocol stack is used by the simulated nodes as well as real-world applications can be used directly during the simulation in NCTUns. Due to this feature, realistic simulation and high fidelity outcomes are achieved by NCTUns.

2.4.5 NCTUns Simulator

The National Chiao Tung University network simulator (NCTUns) (first release on 2002) is one of integrated simulators and emulator where Mobility generator and network simulator are combined in the same environment [43]. NCTUns becomes a commercial simulator since 2012 named EstiNet [45] (figure 2.10 - b).

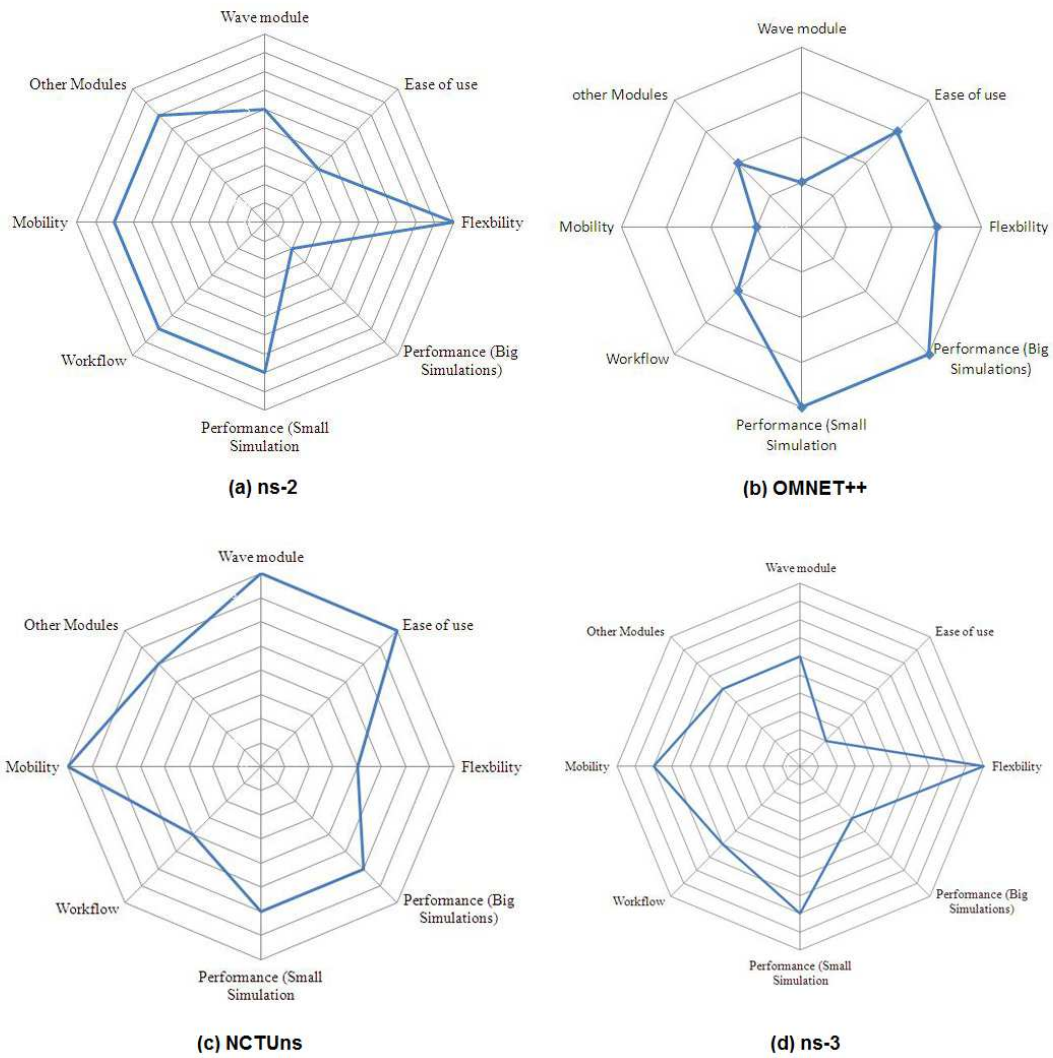

Figure 2.9: Features comparison between different VANETs simulators [8].

However, NCTUns 6.0 is the last non-commercial version which released on 2010 (figure 2.10 - a). Accordingly, my simulation results are generated by NCTUns 6.0 as I do not get access to the newer commercial versions. NCTUns 6.0 must be installed on Fedora 12 which is a well-known Linux distribution.

The main components of NCTUns environment are simulation engine, job dispatcher, coordinator, graphical user interface, car agent, signal agent, applications and Linux kernel patches. Figure 2.11 shows the architecture of NCTUns and the

(a) Free-license NCTUns 6.0 (b) Commercial EstiNet 7.0

Figure 2.10: NCTUns 6.0 and EstiNet 7.0.

interactions among the components of simulator [46]. Indeed, NCTUns has very friendly user interface shown in figure 2.12. Therefore, users can create project, setup models, control simulation execution and generating results easily. In general, simulation models is formed with the user interface. Then, a request is sent to the job dispatcher that looks for a free coordinator for the simulation execution. When the coordinator receives a job, it forks a simulation engine to execute the simulation model dispatched by dispatcher. Later, coordinator declares the results which generated by simulation engine to dispatcher. Finally, simulation and emulation outcomes can be accessed through the user interface.

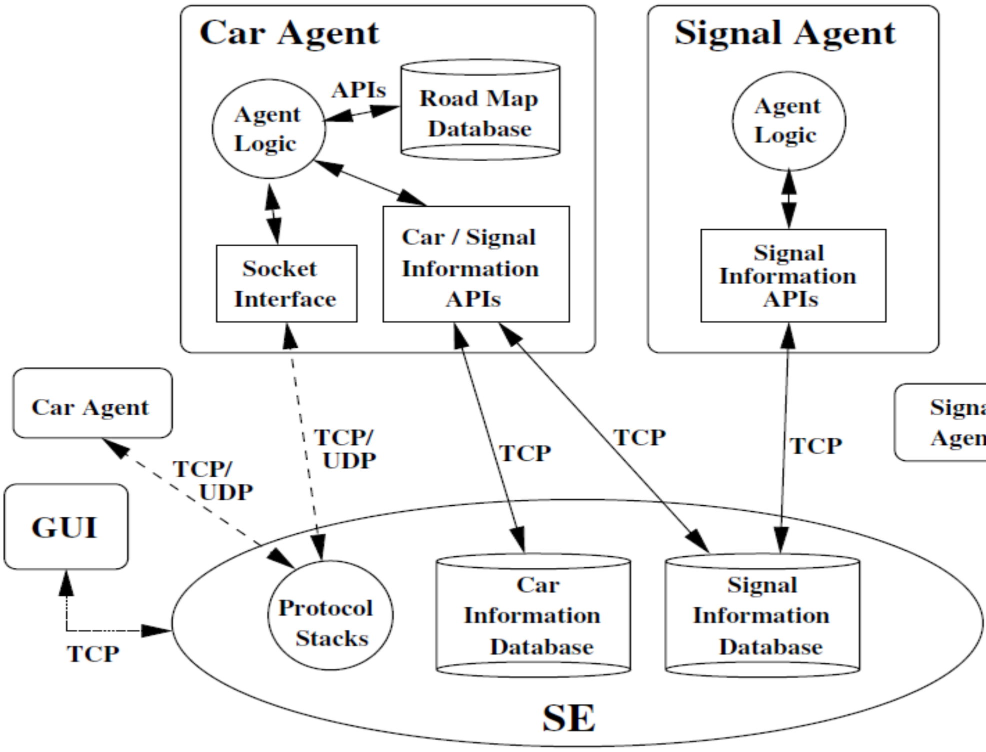

Figure 2.11: The architecture of NCTUns [9].

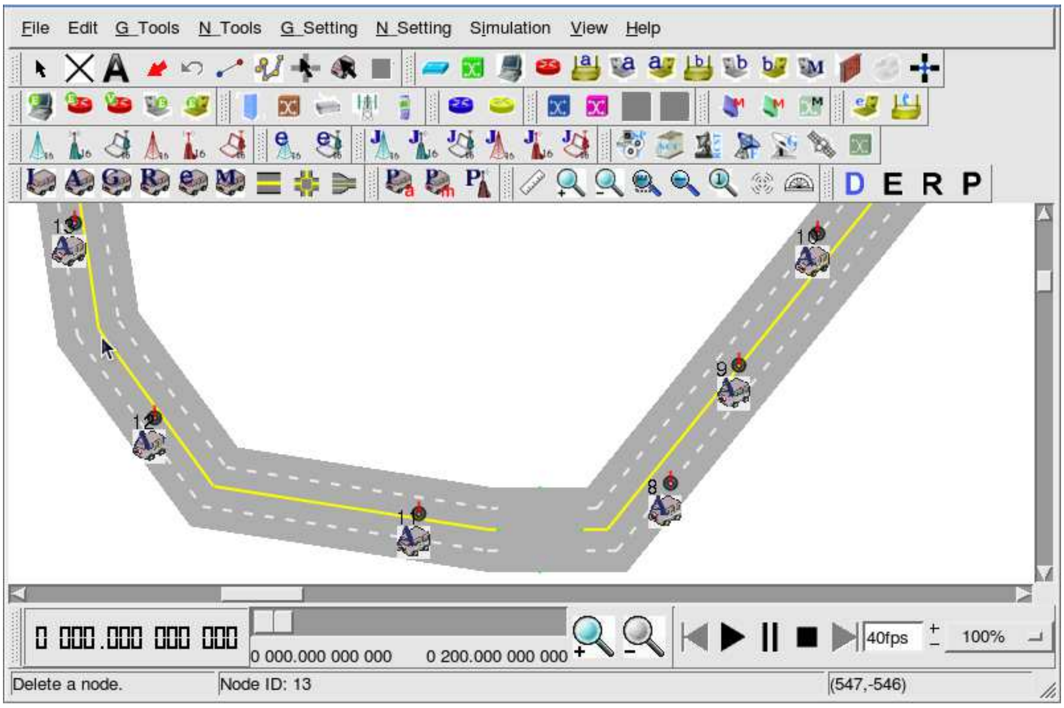

Figure 2.12: NCTUns user interface.

CHAPTER 3

RELATED WORK

Healthcare System are widely studied in nowadays researches, most of them concentrate in monitoring health status of people to provide reports to actors such as people under monitoring, practitioners, coaches for various reasons. The commonly used vital signs are heart rate, pulse oximetry, body temperature, electrocardiography and blood pressure. Collecting and delivering issues has been discussed in vast of researches [2].

Many proposed models have been suggested; some of them are general prototypes such as [20, 17, 47] and others for specific purpose system such as [48, 49, 50, 5]. Some of other healthcare monitoring research are summarized and covered later. Furthermore, the issue of heterogeneity of health monitoring system is studied by researchers. Frameworks and middleware software design are discussed in [51, 52, 53].

Redondi et al. [54] designed a healthcare system called LAURA (Localization and Ubiquitous Monitoring of Patients for Health Care Support) thats providing three functionalities of monitoring, localizing and tracking patient inside nursing institute through wireless sensor network (WSN). Patient status monitoring part classifies the activities of the patients all the time to discover critical conditions. So the medical staff is updated by health status of patients eventually through a wireless channels to provide this crucial data remotely. Moreover, LAURA system provides patient localization and tracking services because of knowing the current place of patients and analyzing their movements help medical staff in urgent aid to perform correct reaction. Also localization and tracking engine use the wireless communication infrastructure for remote delivering of data like monitoring part of system. A centralized and distributed implementation for localization and tracking engine are tested. a centralized solution is to process data centrally not locally in nodes, each node role is to deliver the data without processing and thats provide minimization in power consumption for each node. On the other hand, a distributed implementation is proposed where nodes executing the data and then deliver the localization outcome to the central controller. Advantage and disadvantage of distributed and centralized solutions are discussed in the paper in term of many issues, such as location accuracy, energy efficiency and traffic loads. A real environmental test has been done on LAURA system using commercial hardware.

Cheng and Zhuang [10] proposed a patient monitoring system inside home for early detection of Alzheimers disease using wearable Bluetooth devices for localizing and tracking. A Bluetooth access points are distributed over the house (in each room) to detect wearable device of patient. Patient location and movement pattern can be collected from Bluetooth access points and then saved in local database with its timestamp; proposed system architecture is shown in figure 3.1. These important data is delivered to medical center in a remote site via the internet. A corresponding medical practitioner can then analyze location information and monitor set of behavioural patterns of the specific patient daily. Furthermore, the decision of detecting Alzheimers disease can be handled using an intelligent decision maker by compiling and assembling the daily reported data from home monitoring system of specific patient. Alarm system can be designed to alert both the patient and his medical professional, if there are any early indications of Alzheimers disease. One of the drawbacks of system is due to small coverage range of Bluetooth, so if patient move out of scope then no further information will be reported. Also, throwing the responsibility over Alzheimer patient to wear or carry Bluetooth device is unreasonable.

Rodriguez et al. [11] proposed a monitoring system for sportsman during an exercise session or performing indoor sport activity named Lifewear. Also they designed a semantic middleware to provide complexity abstraction of several of techniques (Standard 802.15.4, standard Bluetooth, Sun SPOT nodes and their equipped sensors, etc.) which has been integrated in the system. This system consists of set of elements (Wearable sensors and Personal devices, Broker, Orchestrator and Sink) where each element plays a significant role of producing, delivering and collecting data. In Lifewear architecture, semantic middleware is

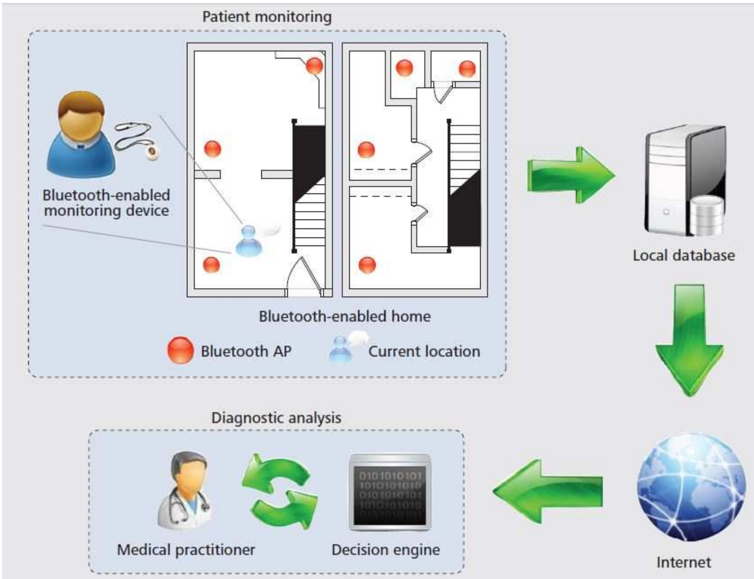

Figure 3.1: in-home patient monitoring system proposed in [10]

loaded in the broker agent so it became the most important part of wireless sensor network. Gymnasium deployment of the Lifewear system is shown in figure 3.2.

Lifewear system [11] provides set of services for gathering information about sportsman health status and context information. And using this services authors claim that evaluation of sportsman performance can be better. Lifewear provides three kinds of services; simple services, composed services and alarms. Simple services is a required information provided by sensors node delivered to the agent when it is requested; no storing or processing in intermediate nodes. Heart rate, Breathing rate, body temperature and context temperature requests are of simple services. Composed services also called sensor virtualization is providing required information based on different reading from nodes of wireless sensor network such as Injury prevention service. Several of indoor scenarios are studied over Lifewear showing feasibility of using different facilities provided and claiming that this

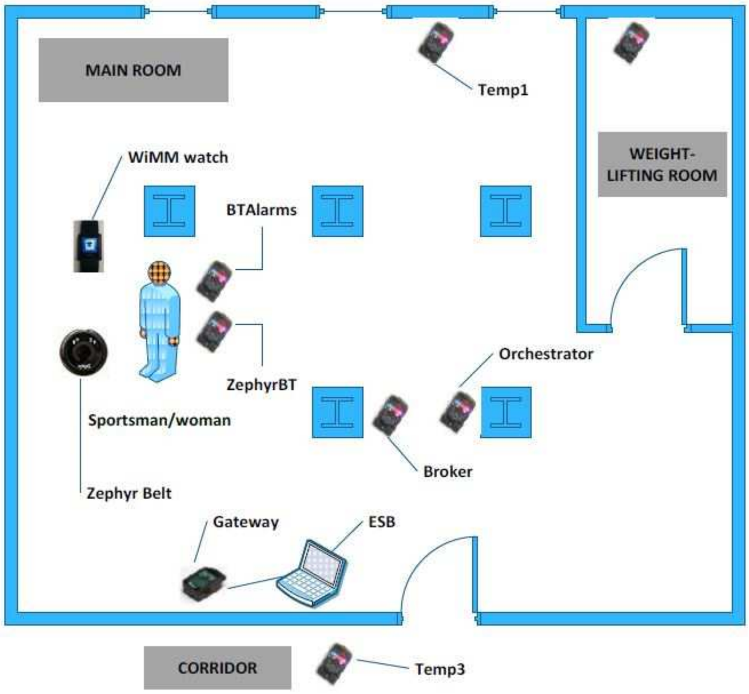

Figure 3.2: Gymnasium deployment of the Lifewear[11] system.

system can be put into real life practice.

Castillejo et al. [55] developed e-health physiological monitoring application for Internet of Things scenarios based on wireless sensor network which aimed to collect data for fire-fighting and sports usages. Three actors are involved in this system; End user application (such as web browser or 3rd party application), Wireless sensor network and human (including sportsman, fitness coach and medical practitioner). Similar to Lifewear project, this application provide three different types of services; simple service, composed service and alarms.

In the same paper [55], an implementation of this application for gymnasium has been tested with real nodes and devices (non-simulated). Graphic User Interface has been built to help sportsman performance by suggesting a series of exercises based on health profile and context information. Status information like breathing rate, heart rate and body temperature are reported from a wearable device such a belt. Each type of these information can be obtained by requesting simple services which done in the same way. Under the principle of sensor visualization as mentioned before, the information obtained from environment and Health status information coming from Body Area Network can be merged to provide one composed service. This can be achieved using nodes with the orchestrator agent. In fact, Alarms are composed notification services. The idea is system will determine some crucial parameters to be sure that health status is under safe condition; if not then all human actors will be informed.

Chen et al. [56] proposed a novel healthcare monitoring system based on a concept for second generation Radio Frequency Identification (RFID) system. In 2G-RFID system, tags store passive information as 1G-RFID system. In contrast, it would store active information encoded in the form of mobile codes reflecting the up-to-date service requirements. Authors discussed advantages that the recommended 2G-RFID system can deliver. This advantage can improve e-healthcare systems in case of information availability, processing of sensitive information, system scalability, information availability and access control. Furthermore, it will advance automated services and emergency response services to be employed facilely.

Benhaddou et al. [57] proposed architecture for remote health monitoring system based on the combination of wireless sensor network and smart phones. A new medium access control (MAC) scheme (MACH) is designed for health sensors to meet the quality of services that are required for emergency health data traffic. MACH was built based on IEEE 802.11e QoS standard for Wireless LANs with significant adaptation; where authors modified its packet scheduling mechanism in pre-emptive service scheduling algorithm.

Wood et al. [12] presented a novel healthcare system inside home based on wireless sensor network for assisted living and residential monitoring named AlarmNet. This system integrates many heterogeneous components of environmental, physiological, and activity sensors. To provide a real-time accessing to data; SenQ query protocol is used which also provide real-time processing in-network.

AlarmNet [12] is a system that consists of five main elements; Mobile body networks, Emplaced sensors, AlarmGate, Back-end and Graphical user interfaces (GUI) as shown in figure 3.3. The health status monitoring and the localization and tracking are achieved by mobile body sensor network. While emplaced sensor network determine context and environmental information such as temperature, motion, humidity. The AlarmGate is the key element which it connect the IP networks to the wireless sensor networks. AlarmGate play the role of gateway between data gathering parts and storing parts. Also it is responsible for privacy, power management, query management, and security. The data delivered form data accumulation parts is stored in the back-end to be analyzed and executed. The outcomes of physiological monitoring, location tracking, context and environmental information can be displayed through GUI that runs on PDA.

Figure 3.3: PDA AlarmNet[12] administration GUI and system architecture.

Venkatesh et al. [58] developed a Smart Ambulance system using an open source tool called Knopflerfish where OSGi middleware is the middleware used to integrate heterogeneity of system elements. Wearable wireless sensor network is used to monitor patient status and report it to medical center to take decisions. Authors used existing application providing traffic directions for the ambulance driver to reach medical center in less time.

In this chapter, we discussed various researches on modern healthcare systems especially in health monitoring. We can observe that, most of these systems are suggested for long term monitoring of patients to collect health status information or localization and tracking information. These collected data might be processed locally or delivered to remote destination for further processing using machine learning algorithms or simply stored then visualized for health professionals. However, collecting and delivering information in emergency cases require critical real-time system because triggered data related to the patient life status instantly. For this reason, patients health status should be advanced to practitioners before reaching the medical center constantly. Furthermore, an automated alerting mechanism must be provided inside ambulances.

CHAPTER 4

E-AMBULANCE PLATFORM

Normal ambulances must be set for all sorts of emergencies. Therefore, most of ambulances contain different medical equipments such as instruments to measure a temperature, pressure and heart rate in patient compartment to report patients status and provide urgent aiding during transporting them to medical centers. Nursing staff inside ambulance use these equipments according to patients medical condition. Also it might contain a communication system to connect to other ambulances and medical centers.

As soon as the patient get the first aid inside the ambulance by nursing staff giving care and deal with the patient who monitored remotely by professionals in the medical center. These medical professionals can help and provide urgent decisions to avoid the patients health getting worse. The vehicle is provided with certain medical equipments in addition they may use sensors and actuators which can keep everything under control . Medical professionals can observe the patients condition directly by reading the reports coming from sensors network unit that provide status information of the blood pressure , heart rate and so on. Of course it depends on the condition which is related to the health status of patient itself. This ambulance can carry one or more(rare case) patient in the same time because there is probability to have such situation especially in disaster cases.

We proposed E-Ambulance model shown in figure 4.1 to provide health monitoring and auto responses in term of alert and suggestions to nursing staff inside ambulances and increase the probability of saving people life and provide better utilization of healthcare costs where most of actions inside E-ambulance are triggered to save patients from life-threatening conditions.

Our model consists of several units where DDS middleware will take place in most of units to hide heterogeneity of these units and control QoSs needed for proposed system. We will describe and discuss the main function of each unit below:

4.1 Sensors Network Unit (SNU)

Wireless sensor network (WSN) development has the significant effect to advance different applications in many fields such as agricultural, industrial, environmental and medical sectors. Terminology of Body Sensor Network becomes more familiar of WSNs due to wide usage of them for healthcare applications [17]. Wireless sensors can augment or replace expensive and cumbersome wired telemetry devices for pre-hospital and ambulatory emergency care when real-time health monitoring of patients is necessary [15, 16]. Alexandros et al. [59] study existing wearable

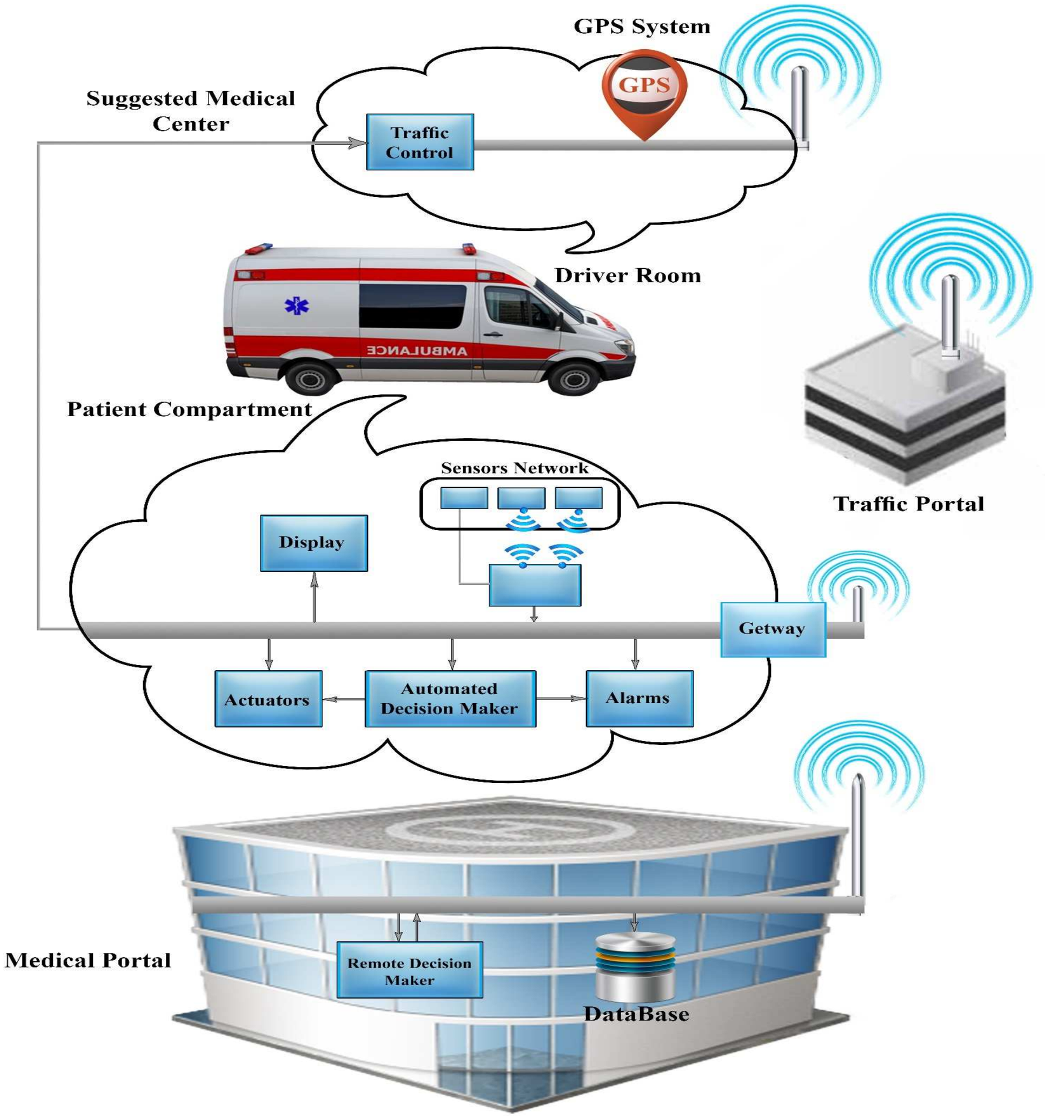

Figure 4.1: E-Ambulance System Architecture.

body sensor networks for healthcare monitoring and discuss recent used sensors in case of types, signals and communication technologies.

A number of wearable biosensors can be attached to patient body inside E-Ambulance; for example, pulse oximeter sensor may bound to patient finger to compute the oxygen saturation and pulse rate. Body temperature, blood pressure, heart rate and other contextual information can be measured by these biosensors nodes and provide real-time delivering flow of vital biofeedback as shown in Figure 4.2. These nodes may have processing unit to process data to deliver only the necessary biofeedback data. These sensors communicate with control device through any wireless technology such as WiFi, Bluetooth and ZegBee to transmit data over short distance. Then this gathered health status information delivers to automated decision maker unit inside E-Ambulance or to remote decision maker located in medical center through a gateway. All of abstraction and communication issues are handled by DDS middleware.

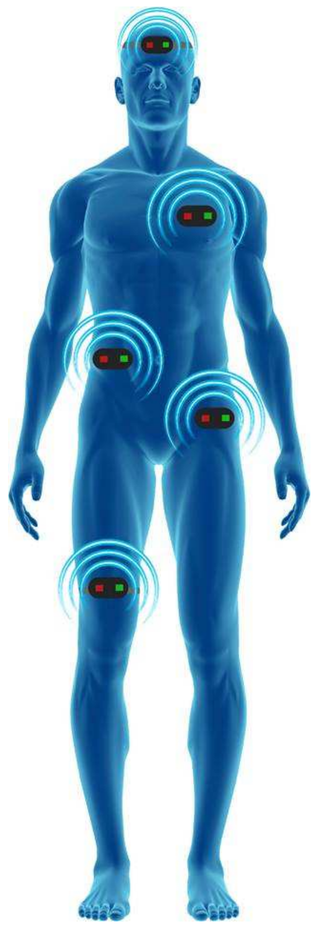

Figure 4.2: Medical Biosensors.

On the other hand, wired biosensors can be used inside ambulance and connected to WSNs through control devices. Connection problem for wired biosensors will occur due to number of wires and limited area of patient compartment. Therefore, there are partially wired devices used in health monitoring; multiple body sensors connect with each other using wires and can transmit data through wireless channel.

4.2 Decision Maker Unit (DMU)

Artificial intelligence researchers try to solve problems using intelligent agents where these agents give an output according to inputs coming from its surrounding environments. Many issues arise to increase chances of success such as reasoning, learning, and the ability of system to manipulate inputs efficiently. The integration of wireless sensor networks and artificial intelligence have built a cross-disciplinary of ambient intelligence to solve problems challenges [17].

In our model, WSNs deliver heath status information to Decision Maker Unit. This unit is responsible to provide warnings or suggestions to nursing staff inside patient compartment by interpreting the data coming from biosensors and provide behavioural patterns. It can provide two types of services; simple service and composed services. Simple services are automatic responses triggered directly according to certain values of vital signs and no further processing is required. Composed services are provided by intelligent agent in this unit which required additional processing of sensors network unit data. Furthermore, one of artificial intelligence technique such as neural network can be used. After manipulating vital signs delivered by biosensors, warnings and suggestions are made and forwarded to actuators and alarms.

4.3 Remote Decision Maker Unit (RDMU)

Typical health monitoring system consists of sensor networks, wireless communication, middleware, and software applications. In our system, sensors network unit generate biofeedback and transmit it to remote medical center through wireless communication. This critical health status information of patient is presented to medical professionals on Decision Maker Room by GUI end software. These professionals can monitor and analyze continuously all health parameters like temperature, blood pressure, heart rate, breath rate and other parameters of patients remotely while transporting patient to medical center.

Professionals may detect a critical situation of patients which need decisive intervention. There are two types of decisive response; first one is by sending suggestions and comments to nursing staff that guiding rescue treatment inside ambulance. Patient status data which delivered by E-Ambulance and responses handled by medical professionals in Decision Maker Room might be recorded in databases located in medical center associated with timestamps. Moreover, end healthcare monitoring application may collects and interprets data delivered directly from remote sources and triggers appropriate responses [20]. The processing part of this end application can analyze data using different algorithms and machine learning techniques to detect any emergency condition of patient

[21]. Additionally, medical professionals can suggest the nearest and appropriate medical center for E-Ambulance driver because it is significant issue to transport patients to suitable medical center which can provide efficient treatment not just to nearest one.

4.4 Actuators and Alarms Unit (AAU)

Actuators in medical field are suggested to improve real-time responsiveness and consistency of patient care. Indeed, actuators function is converting electric signals into mechanical power to sort certain actions. Until the time of writing this thesis, actuators are untrustworthy in modern healthcare systems; accordingly, only few of medical centers around the world use such a type of actuators. Moreover, current medical actuators occupy much space of treatment rooms. Consequently, it is not efficient and mature enough to take place inside ambulances due to lack of confidence and limited area of patient compartment. In particular, future development of implantable medical devices such as pacemakers, cardiac defibrillators, insulin pumps, and neurostimulators (shown in figure 4.3) with all features of wireless connectivity may improve care provider's ability to deliver timely treatment, leading to a better health care system.

Alarms are simple elements in the system which enabled if alerts are triggered to nursing staff inside ambulance. Decision Maker unit inside ambulance and Remote Decision Maker unit send signals to actuators and alarms to provide urgent life-saving actions. Consequently, this unit of our system is mainly concentrated

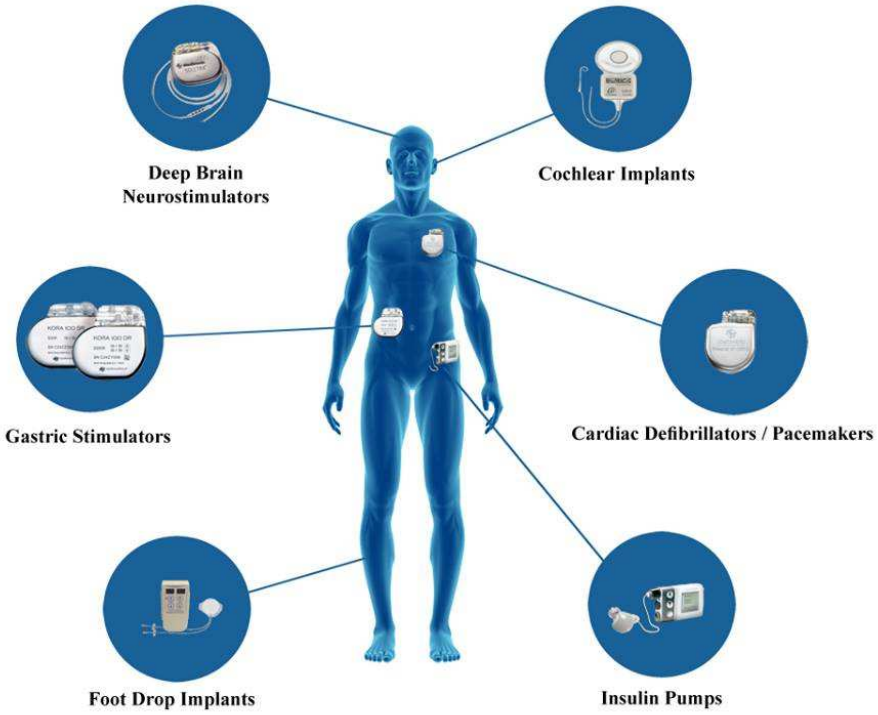

Figure 4.3: Future Medical Actuators.

on alarms but it can be upgraded with the development of medical actuators technology in the coming years.

4.5 Traffic Control unit (TCU)

In many cases ambulance driver need particular guides while transporting patients from origin place to medical center. Tracking and routing techniques can be used to ease ambulance driver job. Global Positioning System (GPS) provides location information with timestamps of E-Ambulance movements during its journeys. This location updates can be sent to medical center and remote traffic management unit (RTMU) for tracking issues. Geographical devices may help the driver by showing maps and routes to pass over traffic jams issues and transport patients into medical center as fast as possible to increase chances of saving their life.

4.6 Gateway unit (GW)

Gateway is responsible to route biosensors data and others messages exchange inside ambulance environment to remote medical portal for further processing, analyzing, logging and visualizing of patient's condition information to medical professionals. Gateway unit is capable to transfer E-Ambulance data to remote destination using different technologies such as cellular network (3G, 4G or 5G) or WIMAX [18]. Furthermore, vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication scenarios for smart vehicles are suitable for such cases. Thus, gateway unit consists of local network interface and one or more interfaces for relaying data through one or more communication systems. Additionally, gateway unit should establish a secure data transmission to provide security and privacy of patient health information in term of confidentiality and integrity. The data must be transmitted to remote monitoring destination such as another smart ambulance or a medical center. Therefore, the success of providing healthcare services depends on robust data delivery.

Different technologies can be used by the gateway of E-Ambulance network such as WiFi, WiMAX, and 3G. In this platform, cellular/WiFi devices can be used for both short and long range communication. V2V communication can provide data exchange platform and facilitate remote monitoring system development. Wireless connectivity, including wireless LAN localization can be dedicated for this type of VAN communication.

4.7 Database and Display

In general, database (DB) in our system is used for logging messages exchange of internal E-Ambulance network parts and remote network parts as well as recording vital signs values of patients. Health information of patients will be stored to central database in Electronic Medical Record (EMR). Later, this information as patients health history may recall for further analyzing and processing for diagnosis and treatment. Furthermore, a local database located inside ambulance might be used to build a log for all internal transactions.

Display or monitor device is used for several functions; an example of this is to show biosensors reading values to nursing staff. A further instance of this is to present comments and commands of medical professionals who monitor patient health state from remote place. Moreover, alerts and warming messages are shown on this device screen.

CHAPTER 5

E-AMBULANCE IMPLEMENTATION OVER DDS

Health monitoring inside ambulance is mission critical real-time system. Where any failure in delivering certain information about patient health status might cause catastrophic consequences such as patients lose their life. Thus, it required fast response time for all actions can be handled. Our real-time solution is built over Data Distributed Service standard which relay on publish/subscribe paradigm.

RTI DSS middleware is a middleware implemented based on DDS specification over Real-Time Publish-Subscribe (RTPS) Protocol [60]. RTI Data Distribution Service is reliable and flexible implementation of a data-centric publish/subscribe communication network and can provide high performing system design which is transport, operating system, and programming language independent.

5.1 Proposed Solution

Our problem is a time critical real-time system where availability, timeliness, performance, reliability are significant requirements. DSS is influential solution in these categories of systems. Furthermore, in our model there are numerous of diverse data sources which connect with numerous of data reception nodes where DDS is can abstract this heterogeneity and provide many to many communication model.

In E-Ambulance system, sensor node publishes vital signs over network which can be wired or wireless network such as WiFi, Bluetooth and ZegBee. Depending on type of service provided (simple or composed) other nodes will response to this publication. If it is simple service then Alarms and Actuators will subscribe this data directly. In composed services, Decision Maker unit provide decision and send it to Alarms and Actuators as a another topic. Figure 5.1 shows this DDS model of communication between elements of this part of our system. Gateway node subscribes to all topics inside the ambulance and delivers it to the remote destination for further processing, logging services or visualizing patients status to medical professionals.

Sensor nodes are devices with limited resources of memory, processing unit, operating system and power. For this sort of devices, lightweight and efficient DDS middleware is required to provide interoperability between these devices network and cooperative networks. RTI bring a convenient solution called Connext DDS Micro Edition [61] targets different embedded system platforms with minimal resources. Connext DDS Micro fulfils challenging real-time requirements and complexity abstraction of integrated networking techniques since it is built based on DDS standard [14] as well as it satisfies demanding resource restrictions. Most of real-time QoS policies including reliability, time filtering, deadlines, resource utilization and system state are supported to supervise real-time requirements. Even though, this solution still require certain level of resources which might exceed the narrow resources of some devices in wireless sensor network. Thus, more lightweight DDS middleware solutions were proposed such as sDDS [62] and TinyDDS [63].

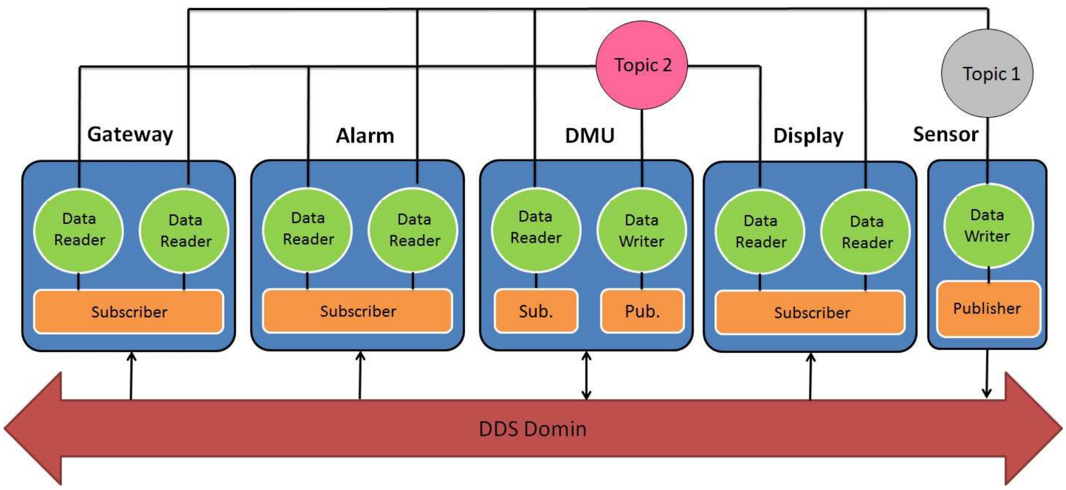

Figure 5.1: DDS model of communication between Sensors, Decision Maker unit, Actuators and Alarms elements of E-Ambulance system.

Each element of our system can be publisher, subscriber or both of a topic or more than one topic as shown in figure5.2. For example, each sensor act as a publisher to send vital signs through network to subscribers which interested to this information. Decision Maker unit is one of subscribers of this vital signs topic; Data will be delivered remotely through internet or WiMAX. Further details about distribution of publishers and subscribers in our system are described in Table 5.1.

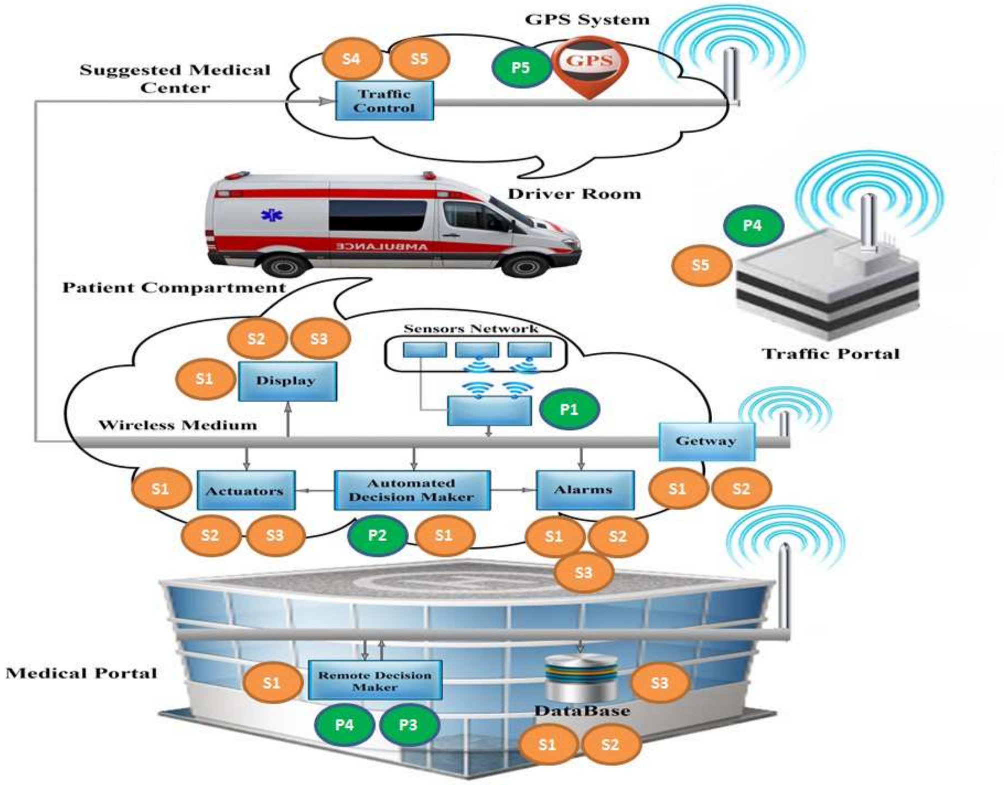

Figure 5.2: Publishers and subscribers nodes in our system.

5.2 DDS Quality of Service Policies

QoS parameters manage a number of aspects of the distribution of topics among nodes. For our system, we concern in some of these Quality of Service policies such as Reliability, History, Resource Limits, Time Based Filter, Deadline, Presentation, Durability and Content Based Filter. In health monitoring system, it

Table 5.1: Description of Publishers and Subscribers in E-Ambulance System

Topic No.	Topic Name	Publishers	Subscribers	Description of Data
1	Biosensors Data	SNU	DMU, AAU, Display, RDMU, GW, DB	Raw data of waveform and parameter sensors
2	Alerts	DMU	Display, AAU, GW, DB	Warning messages produced by alerting mechanisms
3	Professionals Review	RDMU	Display, AAU, DB	Professionals messages in remote medical center to practitioners inside the ambulance such as commands, comments or warming messages
4	Suggested Centers	RDMU, RTMU	TCU	Medical center or traffic control center which are connected with ambulance can send a list of suggested nearest possible vehicle destination to the driver
5	Vehicle Location	GPS	TCU, RTMU	Tracking messages including location and time information of ambulance movements

is acceptable to override a little lose in delivering data for long term monitoring systems. However, E-Ambulance system cannot ignore dropping of critical health status data of patient inside ambulance. DDS Reliability QoS policy care about this aspect by providing two values; RELIABLE and BEST EFFORT. RELIABLE value mean that DDS will attempt to deliver all samples of certain topic and the non-successfully delivered samples will be retried. To ensure reliability, Durability QoS and History QoS policies must be specified because some data should outlive after writing time. Content Based Filter QoS is important in term of simple services provided by the alarms and actuators. Simple services occur in some cases where actions can take place directly by alarms and actuators without dominating by Automated Decision maker Unit. Using Content Based Filter QoS policy, unwanted health status information can be filtered at its normal range. For example, if wearable temperature sensor measure 40 decree body temperature of patient then an alarm will be induced to work.

Using RTI DDS, These functionalities can be set or updated without rebuilding our application by modifying XML file. This profile file contains configurations of QoS policies combination of all DDS middleware elements (such as topic, data reader, data writer and so on) where each value of QoS policy should be specified unless the default value will be set [14]. In most cases, QoS profile must be build based on application needs. For this reason, we mentioned above certain QoS policies govern system resources to satisfy our application requirements. Each topic in our system should be integrated with certain QoS profile that provides efficient system performance over publishing and subscribing process. Therefore, setting certain QoS policies and their values to meet application need is challenging issue.

For biosensor data topic, we used Resource Limits, History, Reliability, and Time Based Filter QoS policies based on topic requirements.

5.2.1 Resource Limits QoS Policy

Resource Limits policy govern the memory resources that can be used by data writer, data reader or the topic itself. Data reader and data writer can handle and store a number of samples up to a maximum samples value in their queue, where the maximum number of sample is determined by this policy. If the number of samples reaches the maximum limit, then the middleware drops samples according to Reliability QoS policy and other policies. The default value of max samples value is LENGTH_UNLIMITED.

5.2.2 History QoS Policy

History policy determines the number of samples connected to data writer or data reader that must be saved in the cache to ensure delivery of samples as a behavior of the service. Two different directions of History policy can be set. First, all samples must be kept until they are successfully delivered to subscribers to guarantee strict reliability (value= KEEP ALL). Second, only the most recent samples will be kept and older samples will be discarded through the service (value= KEEP LAST) where the number of kept samples determined by Depth value (default = 1). KEEP LAST is the default kind of History QoS policy. DDS Micro supports only KEEP LAST kind of history policy because it implemented for limited resources systems. However, values of History QoS policy and Resource Limits QoS policy parameters must be consistent.

5.2.3 Reliability QoS Policy

This policy determines reliability level provided by the service. RELIABLE value of Reliability QoS policy will be used in Biosensor Data topic where the service will put an effort to transmit all samples in services history to the associated data readers. Also, samples will be retransmitted if any failure of delivery occurs. However, due to limited resources and history policy, write operation of new sample into queue or service might be blocked. This happens because of a number of unacknowledged samples in the queue or service and the lack of free space. Maximum blocking time value determines the maximum duration of blocking the data writer, which will then overwrite the existing samples with the new ones.

5.2.4 Time Based Filter QoS Policy

Time-Based Filter QoS policy is a specific data reader policy. It determines minimum separation time. This time period is defined as the interval time where the data reader drops any next samples after receiving the previous one. The default value is zero, which means that the data reader accepts all samples any time. In reliable systems, this policy assists slow data readers in convoying other readers. Additionally, it can also help data readers group and generate data faster than they are able to consume it.

CHAPTER 6

PERFORMANCE EVALUATION OF INTRA-AMBULANCE COMMUNICATIONS

The goal of this work is to propose an ambulance system with a telemedicine architecture. This architecture should meet some requirements of such systems. Skorin-Kapov and Matijasevic [64] summarizes QoS requirements of telemedicine services; a high data throughput is required for tele-diagnosis and consultation and lower in tele-monitoring; and the one way end to end delay constraint for medical data transfer is 300 ms.

In this chapter, we will give a description of our experiments for intra-ambulance communications and discuss the obtained results. In fact, we test three different QoS profiles to get a feasible system performance by regulating QoS policies parameter values. Table 6.1 describes default and tested QoS profiles with their main policies parameter values. In each profile, there are QoS policies that associate with a data reader at the receiver end and another QoS policies that is associated with a data writer at biosensor nodes. As mentioned before, biosensor nodes have limited resources while receiver end has no restrictions in the case of resources. Therefore, KEEP ALL kind for History policy and LENGTH_UNLIMITED max samples for Resource Limit policy are used in the data reader. KEEP ALL kind means there will not be any overwrite operation for received samples by the data reader and all samples will be maintained until the upper layer at the receiver end takes them. Meanwhile, KEEP LAST kind for History policy is used in data writer where its the only supported kind of DDS Micro. On the other hand, RELIABLE kind for Reliability QoS policy is used for all data readers and data writers to ensure that all samples of waveform biosensors are delivered. Other parameters of Reliability, Time Based filter, and Resource Limits QoS policies are tuned for both data readers and writers. Time-Based filter is not used for a slow receiver but rather for fast generation of data, which produces a heavy load at the receiver end.

Table 6.1: Default and Three Tested QoS Profiles Used for Biosensor Data Topic

	QoS Policy	Parameter	Default QoS Profile	QoS Profile 1	QoS Profile 2	QoS Profile 3
Data Reader						
	Reliability	kind	RELIABLE	RELIABLE	RELIABLE	RELIABLE
		max blocking time	100ms	100ms	100ms	100ms
	History	kind	KEEP LAST	KEEP ALL	KEEP ALL	KEEP ALL
	Time Based Filter	minimum separation	0ms	10ms	0ms	0ms
	Resource Limits	max samples	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED
Data Writer						
	Reliability	kind	RELIABLE	RELIABLE	RELIABLE	RELIABLE
		max blocking time	100ms	250ms	250ms	1sec
	History	kind	KEEP LAST	KEEP LAST	KEEP LAST	KEEP LAST
	Resource Limits	max samples	UNLIMITED	UNLIMITED	32	20*

6.1 Experimentation Setup

We have examined our system only in laboratory scenarios not in real world scenarios. In addition, Due to the difficulty of providing actual biosensors for our experiments, instead we built sensor emulator to mimic biosensor communication behaviour learned from [65, 66, 67, 68, 69, 70]. Biosensor emulator generates messages traffic similar to the likely traffic of real biosensors.

In experiment lab, our hardware setup comprised four machines; three machines running biosensor node emulators while the other one running the receiving node (subscriber). All computers were linked wirelessly through IEEE 802.11(WiFi) communication. Localization of different machines used in experiments inside our labs is based on Federal Specification [13] of ambulances. Figure 6.1 show dimensional parameters of ambulance patient compartment [13] and possible location of our proposed system elements. These dimensions were maintained when we ran test experiments in our laboratory.

6.2 Experimental Parameters and Metrics

A part of E-Ambulance which consists of biosensors and receiver is tested and evaluated by measuring DDS middleware performance in term of latency, success ratio, and throughput. After network establishments of this part, we run four set of experiments to compute one way transmission time of data from publishers (biosensors) to subscribers (receiver) by injecting a code to biosensor emulator and the receiver. The success ratio of delivering samples from biosensors to receiver end

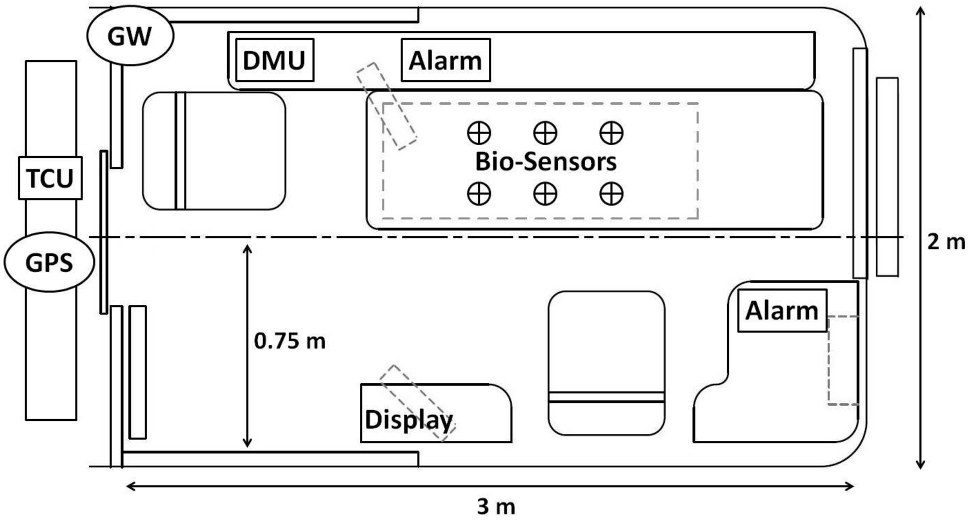

Figure 6.1: Localization of E-Ambulance elements based on Federal Specification [13].

is determined by dividing the total number of received samples at the upper level of application by the total number of transmitted samples. At the same time, wireshark tool is used to measure the throughput which is an average rate of successful message delivery over a communication channel. At each experiment set, the QoS profile of DDS environment is assigned to one of QoS profiles described on table 6.1. Hence, each profile is tested over 4, 8, and 16 publisher associated with different payload size. In addition, each biosensor send 1000 samples with rate equal to sample per 250 ms. Further description of experiments setup parameters is shown in table 6.2. Sample sizes and sampling rate shown in table 6.2 are chosen based on researches mentioned in section 6.1 to cover all cases especially worst cases of emulating biosensors data traffic.

Table 6.2: Experiment Setup Parameters

Parameter	Value
Topic name	Biosensor Data
QoS profile	Default, QoS1, QoS2, QoS3
Number of Biosensors	4, 8, 16
Payload size (byte)	16, 32, 64, 128, 256, 512, 1024
Sampling rate	Sample per 0.25s
Samples count	1000

6.3 Results

The aim of our experiment is to test DDS middleware performance under different QoS policies profiles and scalability of number of biosensors versus data payload size in terms of throughput and communication latencies within the local E-Ambulance network. These performance metrics will give some indication about the most efficient QoS profile for biosensors data topic among other profiles. After running experiments described in the previous section we get results of latency, success ratio, and throughput shown in Tables 6.3, 6.4, 6.5.

Table 6.3: Latency measurement in (ms) for Wireless LAN versus number of publishers and payload size

Number of biosensors	QoS Profile	16 byte	32 byte	64 byte	128 byte	256 byte	512 byte	1024 byte
4	Default	14.467	13.125	16.273	20.224	12.883	32.373	33.001
	QoS1	11.87	19.815	13.984	13.092	16.284	18.213	18.082
	QoS2	187.764	188.705	182.226	183.486	188.573	188.065	189.455
	QoS3	15.718	23.062	14.028	21.025	11.478	20.977	21.467
8	Default	58.059	52.333	63.504	68.997	67.86	90.378	100.948
	QoS1	16.708	44.029	39.659	32.922	49.903	89.513	93.127
	QoS2	178.288	197.08	186.194	188.013	184.281	200.995	207.565
	QoS3	28.387	33.362	42.609	40.264	41.634	70.577	92.153
16	Default	62.149	63.338	91.683	92.978	81.65	96.916	126.087
	QoS1	20.654	38.816	21.496	44.913	52.635	94.652	98.822
	QoS2	116.695	104.801	148.58	139.222	164.322	209.743	200.325
	QoS3	39.54	47.336	51.369	57.378	49.623	69.088	109.114

Table 6.4: Success delivery ratio % measurement for wireless LAN versus number of publishers and payload size.

Number of biosensors	QoS Profile	16 byte	32 byte	64 byte	128 byte	256 byte	512 byte	1024 byte
4	Default	99.00%	98.90%	99.10%	98.90%	97.70%	98.90%	98.80%
	QoS1	99.90%	98.80%	99.90%	99.20%	99.90%	99.60%	98.30%
	QoS2	99.90%	98.90%	99.60%	99.90%	99.80%	98.90%	98.80%
	QoS3	98.70%	99.90%	98.80%	99.70%	99.90%	98.80%	98.90%
8	Default	99.80%	99.00%	98.80%	96.40%	98.80%	98.60%	94.80%
	QoS1	99.40%	98.70%	98.70%	98.70%	98.70%	98.90%	96.80%
	QoS2	97.00%	99.40%	99.60%	99.00%	99.00%	99.40%	98.40%
	QoS3	99.70%	98.80%	99.90%	99.90%	98.80%	99.60%	99.50%
16	Default	99.60%	93.60%	93.40%	93.00%	93.70%	95.20%	95.60%
	QoS1	92.10%	94.00%	93.50%	94.70%	94.30%	94.60%	99.30%
	QoS2	94.60%	99.50%	94.90%	99.50%	95.10%	95.90%	94.40%
	QoS3	93.00%	93.50%	93.20%	93.90%	94.30%	99.10%	99.20%

Table 6.5: Average throughput measurement in (MBitps) for Wireless LAN versus number of publishers and payload size

Number of biosensors	QoS Profile	16 byte	32 byte	64 byte	128 byte	256 byte	512 byte	1024 byte
	Default	0.017	0.018	0.021	0.025	0.034	0.05	0.082
4	QoS1	0.022	0.022	0.025	0.026	0.036	0.051	0.082
	QoS2	0.022	0.023	0.026	0.032	0.036	0.053	0.086
	QoS3	0.03	0.028	0.031	0.034	0.041	0.057	0.088
	Default	0.038	0.42	0.048	0.049	0.068	0.096	0.153
8	QoS1	0.043	0.048	0.051	0.057	0.071	0.102	0.165
	QoS2	0.053	0.054	0.057	0.064	0.078	0.107	0.168
	QoS3	0.057	0.059	0.06	0.067	0.082	0.111	0.173
	Default	0.078	0.087	0.099	0.121	0.146	0.203	0.324
16	QoS1	0.08	0.095	0.099	0.11	0.14	0.203	0.329
	QoS2	0.085	0.098	0.103	0.116	0.145	0.209	0.334
	QoS3	0.105	0.109	0.11	0.124	0.153	0.215	0.342

6.3.1 Latency

We observed that the latency of using profile 2 is very high due to low blocking time. Also, there is no time-based filtering of fast generation of data associated with limited resources as shown in Figures 6.2, 6.3, and 6.4. In Figure 6.2, default profile and profiles 1 and 3 show good performance in terms of latency when 4 biosensors are used. However, latency of profile 1 does not exceed 20 ms, while latency of profile 3 is about 20 ms. Also there is a slightly increase in the default profile when payload sizes are 512 and 1024 bytes. In Figure 6.3, all profiles have similar behavior as in Figure 6.2. However, the latency increases with the increase of data payload, especially with 512 and 1024 sizes. In most cases, profile 1 and 3 indicate auspicious performance in terms of transmission delay (Figures 6.2, 6.3, 6.4, and 6.5). Moreover, profile 1 has slightly lower latency especially when 16 biosensors exist in the system, as shown in Figure 6.4. The maximum latency of QoS profile 2 is 209.743 ms when 512 byte data payload is used for 16 biosensors even though this latency value does not surpass delay requirement for health status monitoring [71].

Figure 6.5 presents latency as a function of number of biosensors while data payload is 128 bytes. All profiles show a decrease of performance when the number of biosensors increases. Again, profile 1 and 3 provide lower latency as well as the latency increases slightly with respect to number of biosensors.

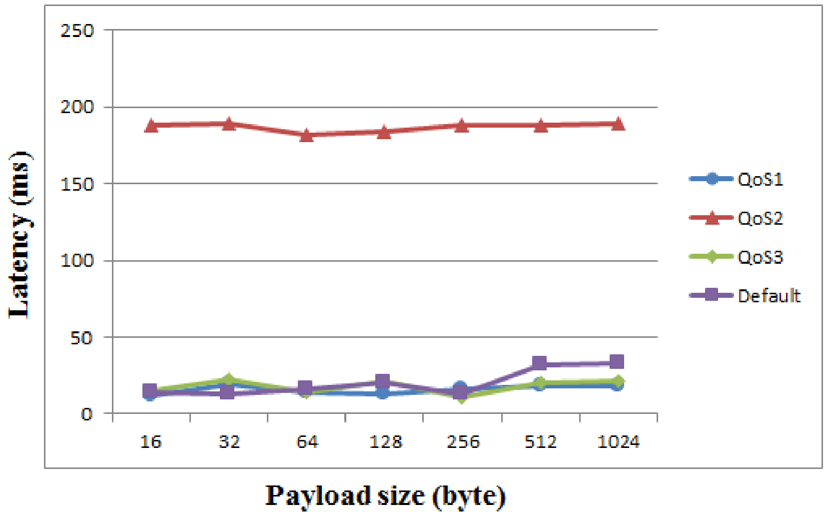

Figure 6.2: Average Latency (ms) versus payload size (byte) of using 4 biosensors.

6.3.2 Success ratio

Figures 6.6, 6.7, and 6.8 present system performance in terms of success delivery ratio of transmitted samples. For 4 biosensors, all QoS profiles reach high success ratio where many cases have 99.9% of samples delivered successfully as shown in Figure 6.6. The minimum success delivery ratio is 97.7% for the default profile with 256 payload size. This delivery ratio is considered to be high. Figure 6.7 shows the success delivery ratio of transmitted samples reaches the maximum ratio of 99.9% for 8 biosensors. Meanwhile, the lowest ratio is 96.4% for the default profile with 128 payload size. Further, most of the cases of profile 2 and 3 have success ratio over 99%. On the other hand, increasing the number of biosensors into 16 nodes will produce heavier traffic load and processing overhead at the receiver end. In Figure 6.8, Profile 2 shows better success delivery ratio because it has no separation time and a reasonable resources limit. Time-based filtering drops packets when heavy traffic is received at the destination node. Thus, there

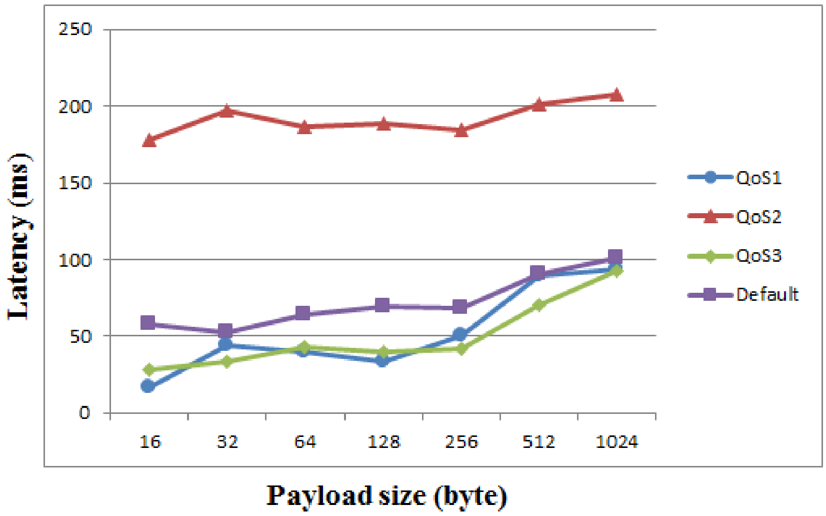

Figure 6.3: Average Latency (ms) versus payload size (byte) of using 8 biosensors.

is a degradation of the success ratio of profile 1. Profile 1 has better success ratios than the default profile even though it has lower resources limits due to its higher duration of blocking write operation before overwriting samples.

Figure 6.9 presents the success delivery ratio with respect to a number of biosensors when data payload is 128 bytes. Success ratio degrades when the number of biosensors increases due to traffic load. Profile 2 has a stable success ratio even when 16 biosensors exist. In contrast, profile 1 and 3 show slight degradation at the same number of biosensors. Default profile presents the worst results of success ratio metric due to lower maximum blocking time value of Reliability policy.

6.3.3 Throughput

Figures 6.10 and 6.11 show the outcomes of the data throughput performance metric. All profiles show good performance in terms of data throughput. Figure

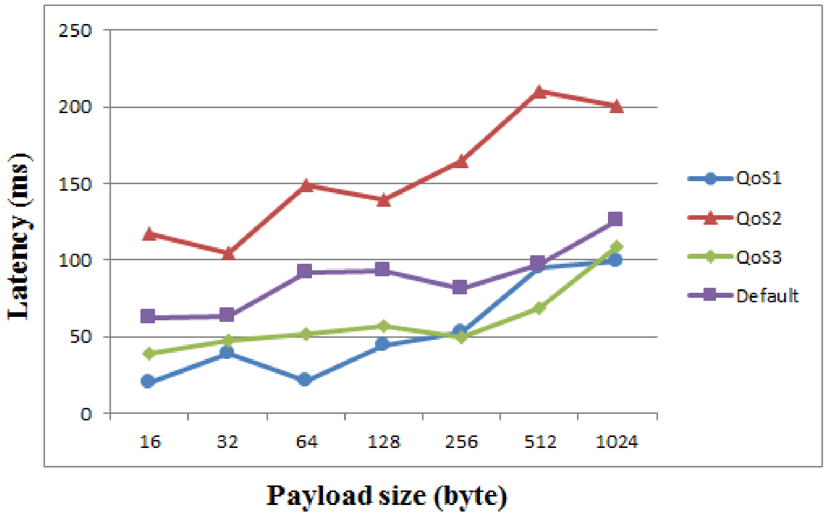

Figure 6.4: Average Latency (ms) versus payload size (byte) of using 16 biosensors.

6.10 shows that the data throughput correspondingly increases as the number of publishers in the system increase and payload size of biosensors data increase. The data throughput of using profile 1, as a consequence of receiver end policy, is poorer than profile 2 and 3 due to the lower success ratio, which is a result of a pause time period of 10 ms for receiving new samples. However, the default profile gained the lowest data throughput outcomes for all setup runs due to the fact that the KEEP LAST history policy kind is used at the receiver end. Accordingly, we set KEEP ALL history policy kind at the receiver end to guarantee reliability with minimal resources biosensors.

Moreover, Figure 6.11 presents average throughput per biosensor of all experiments runs to show how throughput of each biosensor was affected by increasing the number of biosensors. More simply, we produce these results by dividing overall throughput by the number of biosensors. Clearly, all profiles outcomes prove a scalability behavior of DDS despite the very small amount of degradation that

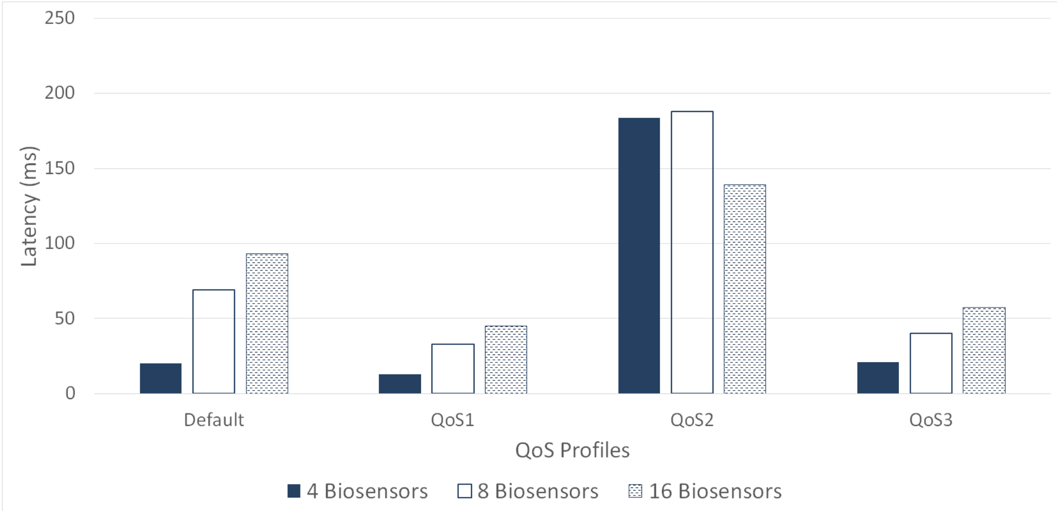

Figure 6.5: Average Latency (ms) as a function of number of biosensors with a data payload of 128 bytes.

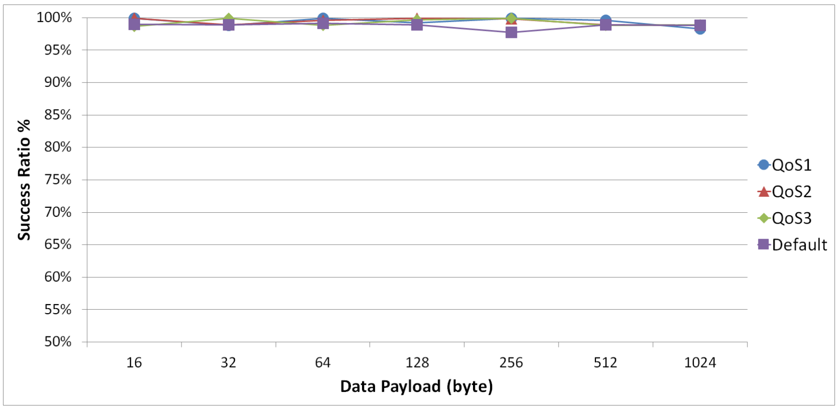

Figure 6.6: Success delivery ratio % versus payload size (byte) of using 4 biosensors.

appears when the number of biosensors increases. An instance of this is when maximum degradation of throughput per biosensors for 128 byte data payload is less than 0.0001 Mbits/s.

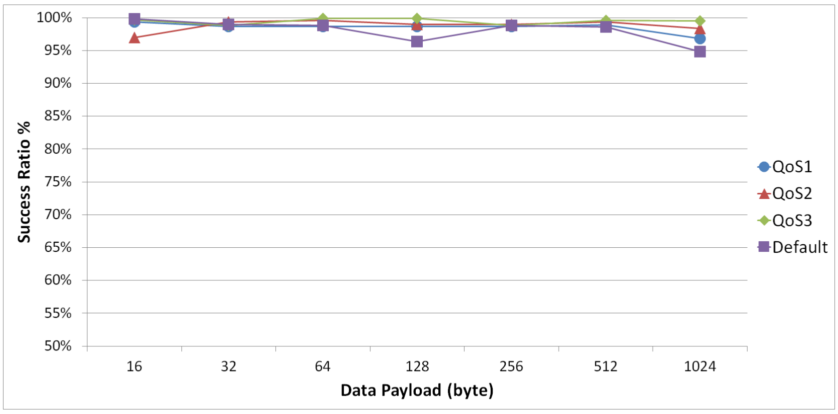

Figure 6.7: Success delivery ratio % versus payload size (byte) of using 8 biosensors.

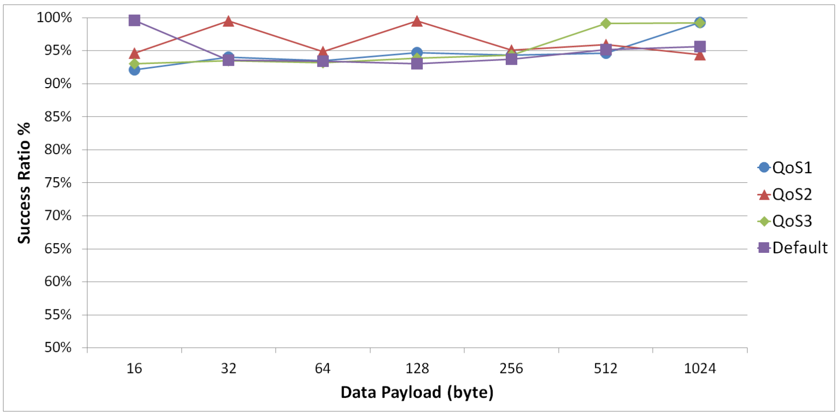

Figure 6.8: Success delivery ratio % versus payload size (byte) of using 16 biosensors.

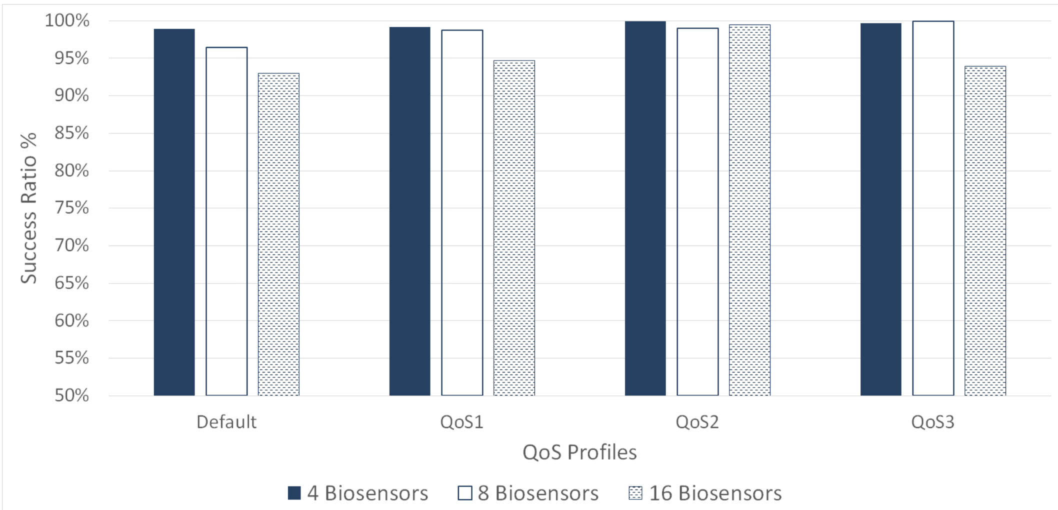

Figure 6.9: Success delivery ratio % as a function of number of biosensors with a data payload of 128 bytes.

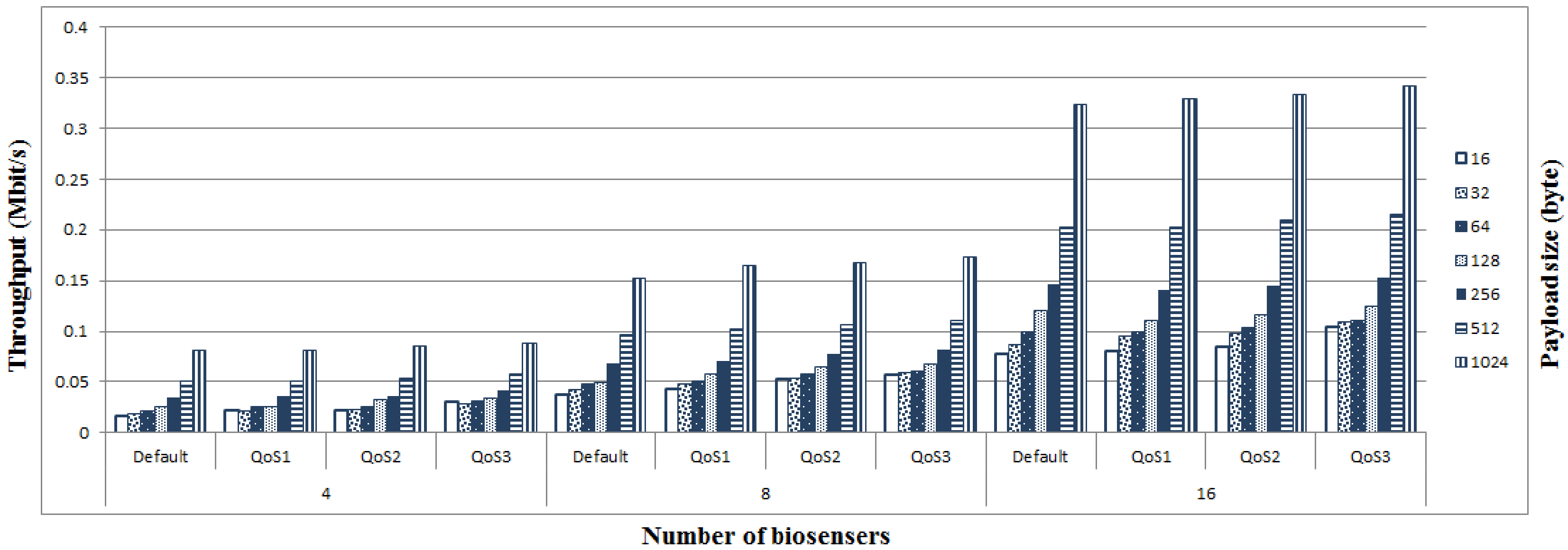

Figure 6.10: Average overall throughput (y-axis) in (Mbits/s) for Wireless LAN versus number of publishers (x-axis) and payload size in (bytes).

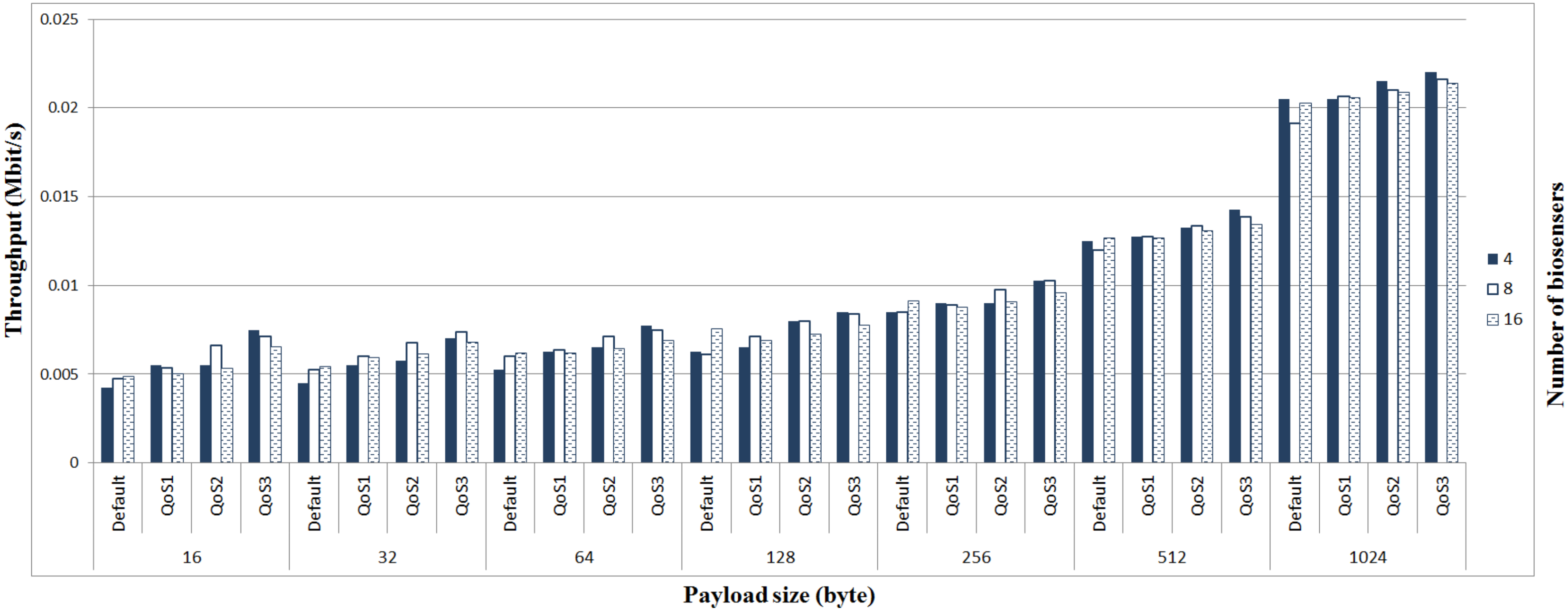

Figure 6.11: Average throughput per biosensor (y-axis) in (Mbits/s) for Wireless LAN versus number of publishers and payload size in (bytes).

6.3.4 General observation

The above-mentioned outcomes show that E-Ambulance system architecture over DDS middleware is efficient and scalable. The probability of having high latency growths when the number of biosensors and their data payload rises is due to weighty network traffic. These data transmission delay results of all QoS profiles dont surpass the eHealth system requirements of typical latency constraints for biofeedback data gathering. Cavalcanti et al. [65] and Ibarra et al. [71] claim that the upper constraint of latency is 250 ms while Liang and Balasingham [68] and Chevrollier and Golmie [69] claim the constraint is 500 ms. QoS profile 3 gets the top outcomes among other QoS profiles for all metrics as a result of balanced and consistent policies parameters. Where profile 3 has limited finite resources that constraints memory growth, it also has higher blocking time which makes the system more performant and robust by decreasing the number of overwriting. However, the minimum separation period of 10 ms reduces the performance of profile 1 where the unlimited resources of publishers do not improve the performance. On the other hand, profile 2 presents the highest success ratio among other profiles, although it has poor performance in terms of latency.

CHAPTER 7

PERFORMANCE EVALUATION OF INTER-AMBULANCE COMMUNICATIONS

Due to the difficulty to find complete approach for implementing vehicular based application scenario as a result of its complexity, we partially reviewing and evaluating a possible design that supports our proposed peer to peer application. Actually, many aspects must be considered while implementation and testing process such as mobility, topology, speed, inter-connection probabilities, etc. therefore, using approaches that reflect real vehicular aspects is imperative. In vehicular network simulation, the realism of outcomes comprehensively depends on relativity of used mobility models to the real life mobility scenario.

In this chapter, we aim to describe network properties and test case scenario that used for simulations implementation. The test case of our simulation is Hajj pilgrimage in Makkah. Makkah scenario has been implemented to evaluate inter-ambulance communications through different network configurations and simulation parameters.

7.1 Hajj pilgrimage and Makkah City

The most important holy places for Muslims are exists in Makkah and Medina, Saudi Arabia. In the pilgrimage season called Hajj, Around 2 million pilgrims come to Saudi Arabia annually to perform this essential worship. According to Central Department of Statistics and Information Ministry of Economy and Planning, The total number of pilgrims is (1.952817) million where 71% of pilgrims from outside Saudi Arabia, and the rest 29% are from inside the kingdom [72]. Saudi Arabia government face various challenges of regulating this annual event. Housing, transportation, safety, security and healthcare are needed services must be considered by local authorities. Thus, well planned cooperation among numerous agencies and departments is required to ensure satisfactory services [73].

Every year, The Ministry of Health (MOH) [74] seeks to maintain health and safety of pilgrims by handling healthcare services and facilities which support all their needs at various levels of preventive, diagnostic, therapeutic and emergency and awareness. The delivery of therapeutic and emergency facilities takes place through a network of healthcare centers. In Makkah, MOH announced that 25 hospitals and 140 medical and emergency centers are enrolled during hajj pilgrims to receive any emergencies cases may occur by the presence of large numbers of pilgrims in the pilgrimage area.

Figure 7.1 shows the Makkah map and the distribution of hospitals and medical centers over the pilgrimage areas [75]. Where the dimensions of tested area is 22 x 16 km^2 includes the three main pilgrimage places; Al Haram, Mina, and Arafat.

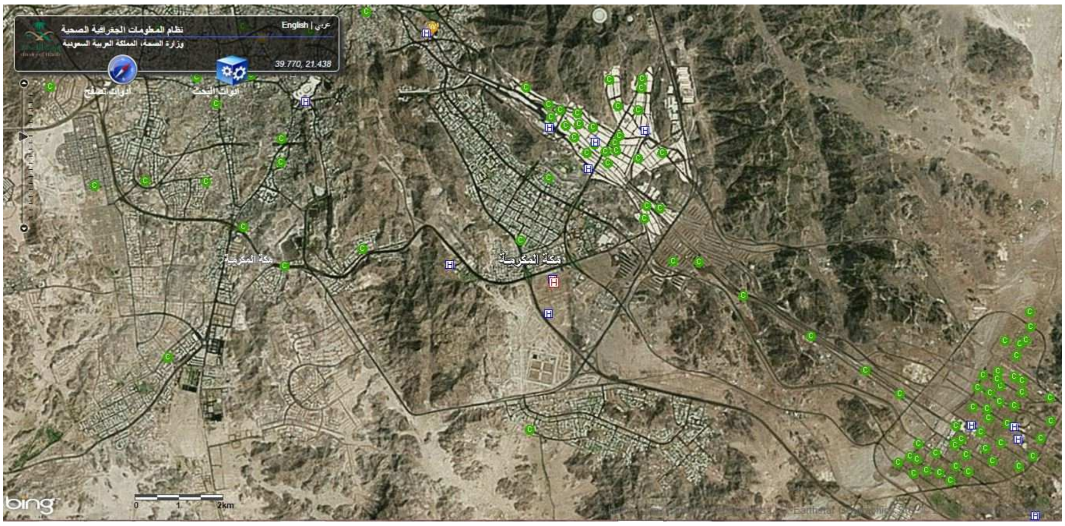

Figure 7.1: Makkah city map with the distribution of medical centers.

Accordingly, Makkah City during Hajj pilgrimage is the best choice to implement our proposed system. Many critical health status cases of pilgrims reported during pilgrimage season and the need occurs of transporting them from their place to the nearest medical center or sometime it requires to transport them to hospitals. Ambulances is the way to transport such cases. Normal ambulances must upgraded to smart ambulances such as E-Ambulance due to many reasons. First, ambulance may arrive to the destination with high delay because of crowded roads. However, according to the requirement of large number of medical practitioners, MOH enrolls nurses under training and volunteers. Hence, the quality of patient treatment inside ambulances for critical cases will be lower. Finally, Medical professionals who have high chance to save their life are serving in medical centers.

E-ambulance platform can provide substantial solution to medicate and save patient people from life-threatening state in Hajj pilgrimage. Because it offers full monitoring of patient during ambulance trip as well as auto responses of health status parameters switching.

7.2 NCTUns Environment

As mentioned in section 2.4 to study a system of vehicular networks, a tightly integrated platform is required to run mobility and network simulation simultaneously. Accordingly, integrated simulators are the optimal solution for such systems as our proposed ambulances system. Also, features charts of widely used simulators (ns-2, OMNET++, ns-3 and NCTUns) are shown in figure 2.9. Most of simulators does not support IEEE.11p (WAVE) standard in their environment. While NCTUns is a vehicular simulator and has full support of IEEE 802.11(p) in its 6.0 version. Moreover, NCTUns supports different mobility and control models for vehicles movement, road and map construction, and road side infrastructure. Apart from this, Linux TCP/IP protocol stack is used by the simulated nodes as well as real-world applications can be used directly during the simulation in NCTUns. Due to this feature, realistic simulation and high fidelity outcomes are achieved by NCTUns.

As mentioned in section 2.4.5, the main components of NCTUns environment are simulation engine, job dispatcher, coordinator, graphical user interface, car agent, signal agent, applications and Linux kernel patches. Indeed, NCTUns has very friendly user interface shown in figure 2.12. Therefore, users can create project, setup models, control simulation execution and generating results easily.

Therefore, we installed NCTUns 6.0 core on Fedora 12 which is a well-known Linux distribution using virtual machine software (Oracle VM VirtualBox). we run the virtual machine in ASUS laptop with Intel(R) Core(TM) i5 CPU at 2.5GHz and 6 GB of memory. Then, we built Makkah simulation scenario using its user interface and set network configurations and simulation parameters as described in next sections.

7.3 Scenario Description

Figure 7.1 shows the Makkah map and the distribution of hospitals and medical centers over the pilgrimage areas [75]. Where the dimensions of tested area is 22 x 16 km^2 includes the three main pilgrimage places; Al Haram, Mina, and Arafat.

Figure 7.2 shows the simulation Makkah map in NCTUns 6.0 which consists of the main Hajj places; Al Haram, Mina, and Arafat. The symbol (H) represents the medical center and the (H) surrounded by pentacle shape is the King Abdullah Medial City. The road intersections which dotted by orange are used to mimic crowded places by enabling traffic lights. The tested scenario comprises of a

VANET deployed over a Makkah map. Twenty two base stations distributed over city map which present medical centers.

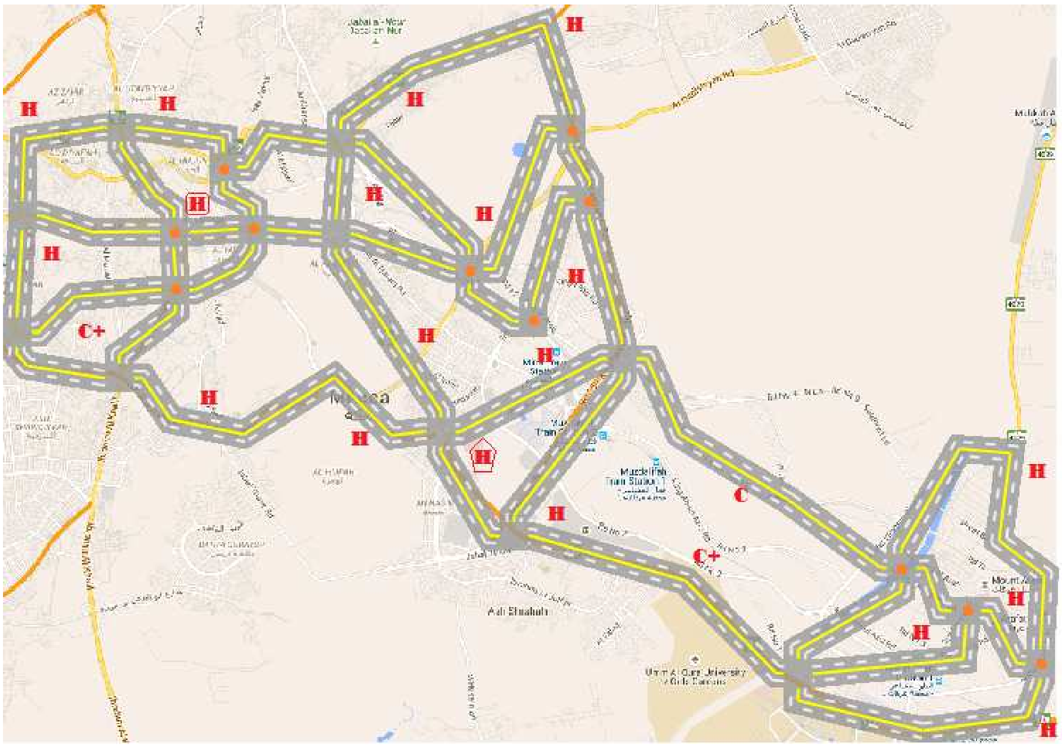

Figure 7.2: Makkah city map implementation in NCTUns 6.0.

Source vehicle transmit medical information to the destination base station. The deployed network has to rely on multi-hop to deliver data because the destination node could be out of source transmission range. The transmission range of each node was set to 250 meters as we built the simulation model over IEEE 802.11p protocol.

For all simulation configuration, the simulation run time set to 80 seconds. We believe this duration is enough for testing simulation model. The scenario shown in figure 7.3 has common simulation configuration such as:

- 3000 x 2200 m^2 scaled dimensions of real Makkah dimensions due to NCTUns

Figure 7.3: Simulation model in NCTUns 6.0.

simulator area restriction.

- The simulation time is configured to be 80 seconds.

- In each simulation run, there is only one data connection. The destination of all data traffic is the King Abdullah Medical City.

- Each medical center acts as base station (or RSU).

- IEEE 802.11p protocol is used to handle all inter-vehicle communications in our simulation model.

- The transmission range is set to 250 meters.

- A multi-lane configuration for traffic flow. The lanes wide is 40 meter with 2 opposite direction lanes.

- A traffic lights configured to mimic slow movement of vehicle in crowded

Table 7.1: Vehicles Speed Levels

Level	speeds (km/h)	percentage of each speed
30	21.6, 25.2, 28.8, 32.4, and 36	20%
70	64.8, 68.4, 72, 75.6, and 79.2	20%
120	111.6, 115.2, 118.8, 122.4, and 126	20%

areas.

- The initial vehicles speed is set to zero.

7.4 Parameters of the Simulations

Simulation scenario built under different levels of vehicle density where the number of vehicles is 50, 80 and 100. Moreover, three levels of vehicle speed is tested named level 30, level 70, and level 120. It should be noted that each level has 5 different speed distribute over the number of vehicles equally. For example, speed level 30, 20% of nodes move with 21.6 km/h speed, 20% of nodes move with 25.2 km/h speed, 20% of nodes move with 28.8 km/h speed, 20% of nodes move with 32.4 km/h speed, 20% of nodes move with 36 km/h speed. Table 7.1 shows different speed profiles for each speed level. In addition, the payload size of data connection is 1 KB, 4 KB, 7 KB, and 10 KB to test performance of implemented model over different connection properties.

The values parameters of simulation scenarios and their description as well as network configurations in NCTUns 6.0 are presented below:

- Density of vehicles is set to be vary from scenario to another where number

Table 7.2: Simulation Parameters

Parameter	Value
Simulation Area	3000 x 2200 m^2
Simulation time	80 sec
Number of vehicles	50, 80, and 100
Physical layer	IEEE 802.11p
Transmission range	250m
Routing protocol	AODV, DSDV, and DSR
Transport protocol	UDP
Payload size	1KB, 4KB, 7KB, and 10KB
Mobility model	CarAgent_LaneSwitch (NCTUns)
Driving Model	Intelligent Driving Model (NCTUns)
Traffic lights	Agent control (NCTUns)
Vehicle speed levels (km/h)	30, 70, and 120
Number of lanes	4 (2 in each direction)
Lane width	20m

of vehicles is varies from 50 to 100 vehicles.

- Different level of vehicles speed (30 km/h, 70 km/h, and 120 km/h).

- Three different routing protocols are used through the simulation (AODV, DSR, and DSDV).

- Different payload size are used for simulation (1KB, 4KB, 7KB, and 10KB).

The simulation was run for all the combinations of simulation parameters described before in NCTUns 6.0. Summary of network configurations and simulation parameters is shown in Table 7.2.

7.5 Performance Metrics

In order to evaluate the performance of simulation model, different performance metrics are used. In this research, throughput, end to end delay, packet drop, and packet collision are selected to check the performance of simulation model of Makkah city. A brief description of the selected performance metrics is presented below:

7.5.1 Throughput

Throughput measures the efficiency of system in delivering data through the network from source to destination. In other words, Throughput determine the number of data packets which delivered successfully in term of packets per seconds or bytes per seconds.

7.5.2 End to end delay

End to end delay is the average transmission time needed for packets to travel through the network channel from source end to destination end.

7.5.3 Number of dropped packets

This metric determine the total number of data packets that fail to transmit into the destination successfully. Packet drop occurs through network due to different reasons such as faulty hardware, congestion, signal degradation, etc. In fact, higher drop rate reflect lower system performance.

7.5.4 Packet collision

This metric determine the number of data packets that discarded or sent back as a result of a collision among them. Collision occurs when two or more nodes try to transmit at the same time. In fact, higher collision rate reflect lower system performance.

7.6 Simulation Results

7.6.1 Study the effects of Infrastructure stations

Figure 7.4: RSU effect simulation model.

In this section, we study the impact of integrating infrastructure provided by RSUs to vehicular communications. A simple scenario shown in figure 7.4 is built

Table 7.3: Comparison of System Performance with and without RSUs.

Performance Metric		Total	Mean	Max	Min
Throughput (kb/sec)	with RSU	18951.994	236.899925	350.08	0.098
	without RSU	16847.548	210.59435	346.798	1.134
Drop packet	with RSU	29519	368.9875	631	145
	without RSU	30534	381.675	651	149
E2E delay (msec)	with RSU	-	8.206	515.217	1.293
	without RSU	-	5.491	242.958	1.293

to analyze network performance with and without RSUs in term of throughput, end to end delay and drop packet. First, we ran simulation without adding RSUs and collected performance metrics. Then, we ran same simulation model after adding five RSUs and collected performance metrics for comparison. In this model, AODV protocol is used with 1 kilobyte data payload.

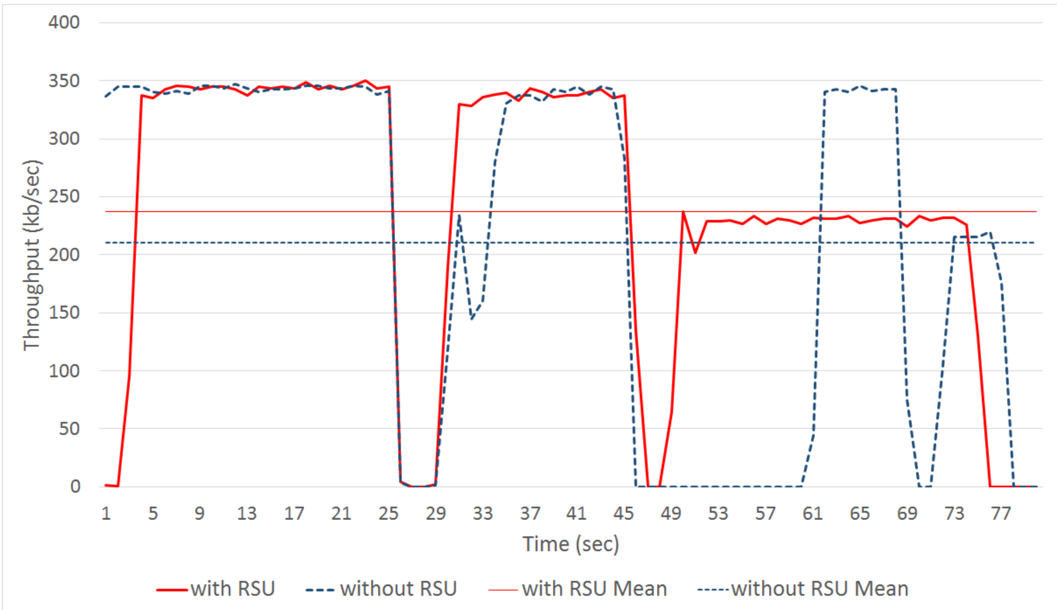

Figure 7.5: Throughput of vehicular model with and without RSUs as function of simulation time.

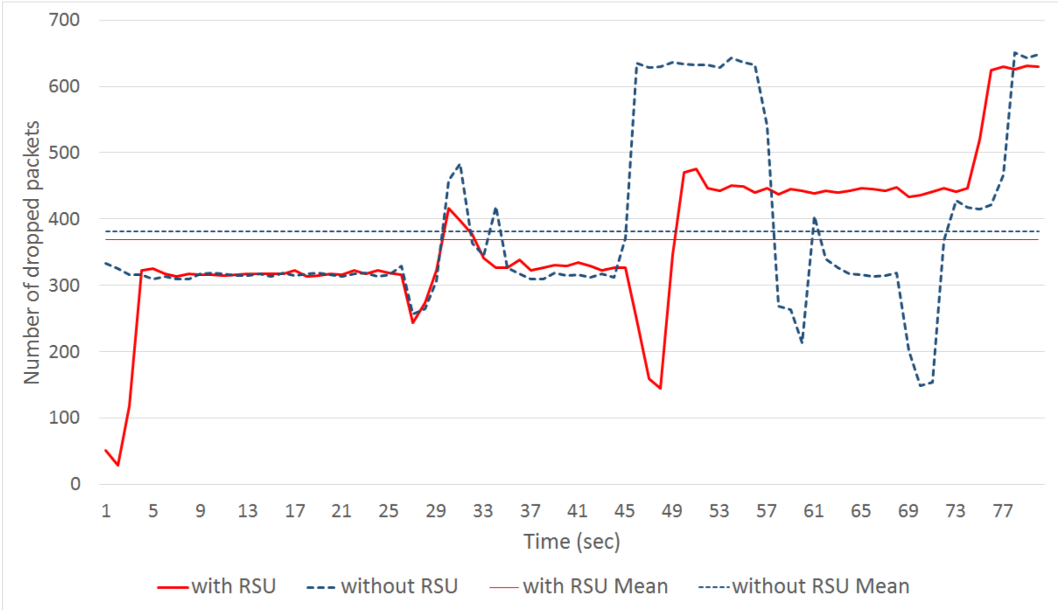

Figure 7.6: comparison of total number of dropped packets when RSUs are implemented and not as function of simulation time.

Results values of using RSUs surpass results obtained from a model without RSUs as shown in Table 7.3. The integration of infrastructure in delivering data in vehicular networks visibly improves performance as higher average data throughput and lower total number of dropped packets are gained. Figure 7.5 shows larger disruption of data connection between source and destination. In contrast, due to the existence of RSU nodes the obtained route nodes by routing protocol are usually available and not out of transmission range. However, using RSU nodes may get lower throughput and high packet drop rate as a result of number of hops for obtained data route as shown in figures 7.5 and 7.6. Even though, a slight increase of end to end delay occurs when using RSUs due to longer paths (number of hops) are used to deliver data. However, this increase in delay is not more than 3 milliseconds in average.

7.6.2 Study the effects of vehicle density and speed

In this section, we focus on vehicle density and speed effect on our vehicular model. Figures 7.7, 7.8, 7.9, 7.10, 7.11 and 7.12 obtained as function of vehicle density and speed level while AODV protocol and 1 kilobytes data payload are used.

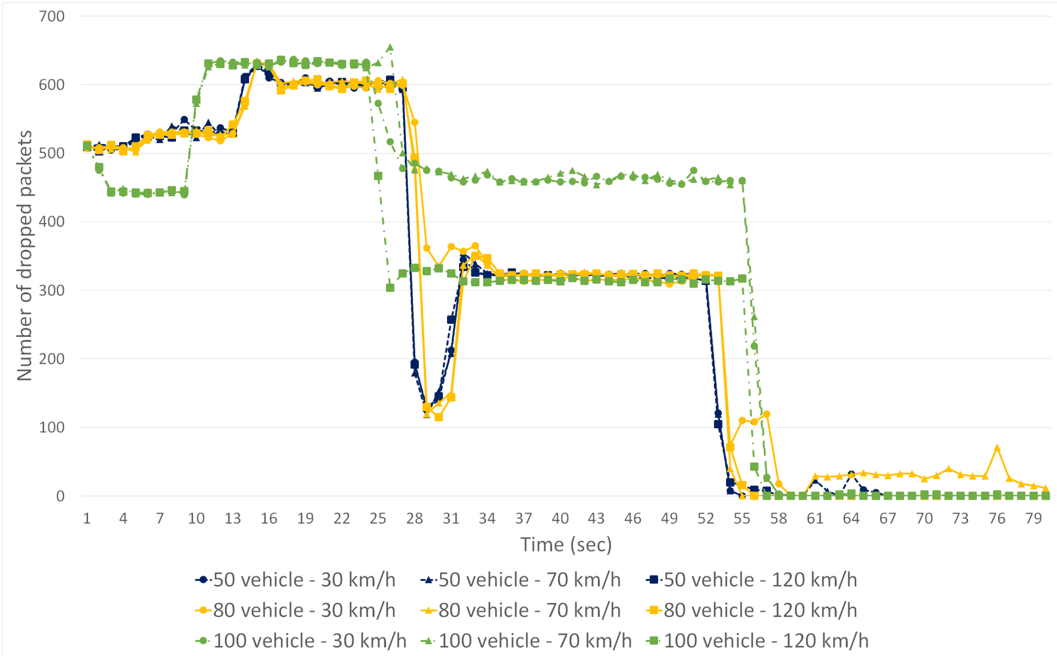

Figure 7.7: Number of dropped packets of different combinations of vehicle density (50, 80, and 100 nodes) and speed (30 km/h, 70 km/h, and 120 km/h).

Figure 7.7 shows the number of dropped packets against time in seconds. Clearly, increasing number of vehicles into 100 vehicles cause a high rate of packet drop. When the number of vehicles are 50 and 80 vehicles, the number of dropped packets seem to be the same.

Figure 7.8 shows the packet collision variation over simulation time. When the number of vehicles is 50, it gives the lower collision rate for all speeds. While, the highest value is when 70 speed level deployed for 100 vehicles. Furthermore, 80 number of vehicles show higher collision at certain time when 70 and 120 speed

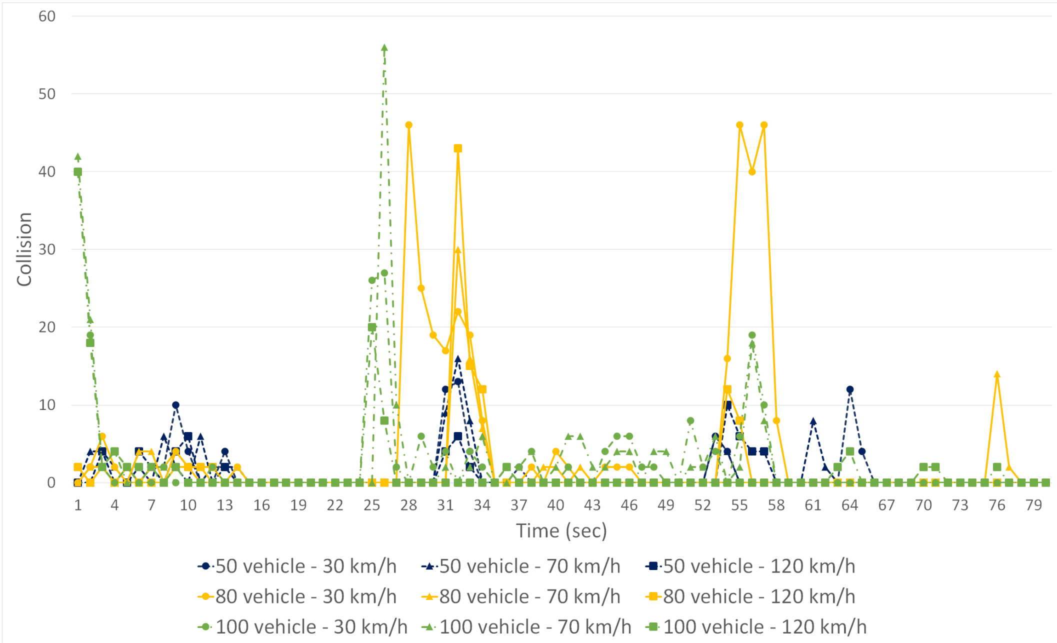

Figure 7.8: Number of collisions of different combinations of vehicle density (50, 80, and 100 nodes) and speed (30 km/h, 70 km/h, and 120 km/h).

levels are used.

Figure 7.9 shows the data throughput in kilobyte/sec over simulation time. Obviously, the throughput degraded to zero in all tested combination for 15 seconds simulation time. This occurs because the source cannot establish a data connection to destination. Most likely the reason is one of route nodes are out of transmission range including source and destination node which depends on routing protocol behavior. Accordingly, the packet drop rate is high during the same duration. Apart from this, the data throughput behavior against time is similar for all speed levels and vehicle density.

Figure 7.10 presents the total number of dropped packets as a function of vehicle density and speed. As the number of vehicles increase the number of dropped packets increase. This behavior happens because higher node density

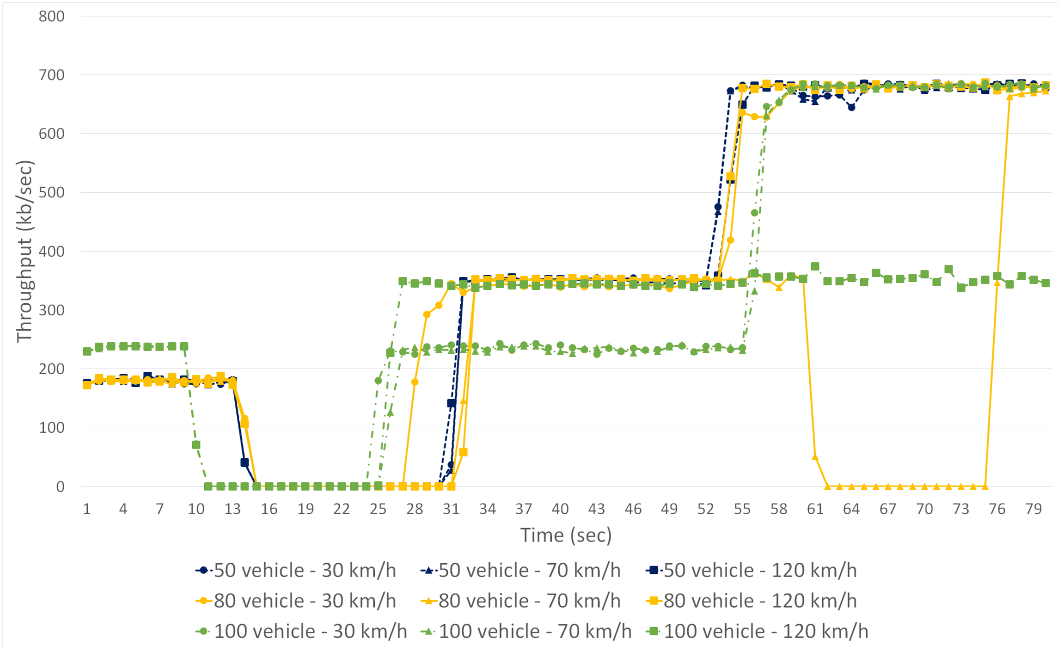

Figure 7.9: Data throughput of different combinations of vehicle density (50, 80, and 100 nodes) and speed (30 km/h, 70 km/h, and 120 km/h).

causes higher drop packet rate due to high probability of congestion and transmission failures. In term of speed level, lower vehicle density with higher speed level has lower packet drop. For instance, packet drop of normal vehicle speed level such as 30 km/h and 70 km/h is higher compared to high speed level such as 120 km/h. In normal vehicle speed level, the number of dropped packets is most likely equal but speed level 70 is slightly lower.

Figure 7.11 shows the average end to end delay results with respect to the number of vehicles and their speed level. Obviously, high delay is gained with high number of vehicles. On the other hand, when the number of vehicles is 50 and 80, lower end to end delay is gained where the highest delay is 18.091 milliseconds when 80 vehicles are deployed with 70 km/h speed level. Additionally, the transmission delay increases as the vehicles move fast. Whereas, the end to

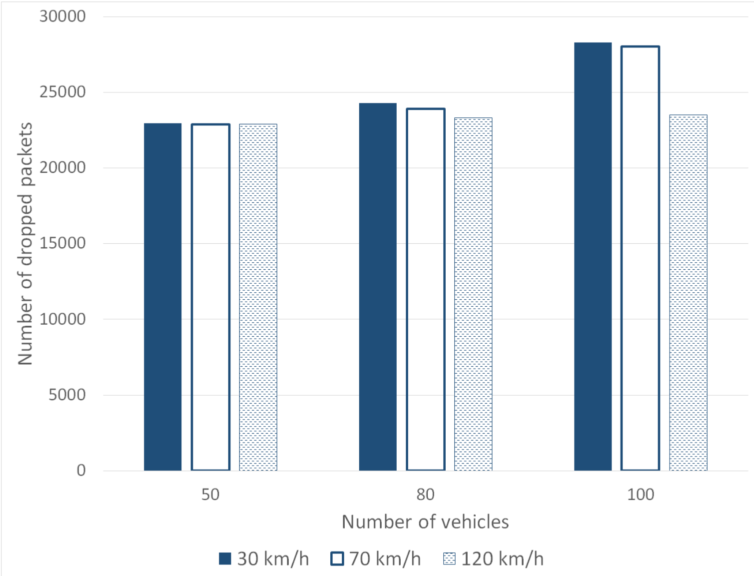

Figure 7.10: Total number of dropped packets as a function of vehicle density and speed.

end delay proportional to the number of hops in the obtained routes for data transmission.

Figure 7.12 presents the average data throughput as a function of vehicle density and speed. The highest average throughput is 363.0317 kb/sec of 80 vehicles network with speed level 30. In higher density network such as 100 vehicles cases, the average throughput decreases due to higher packet drop and collision rate. Throughput values of high speed level cases is lower compared to others. This behavior is consistent since at high speed level, packet drop rate is higher as discussed previously. Furthermore, data throughput is stable for 50 vehicle cases even though speed level is increase. Moreover, data throughput of normal speed cases is slightly equal.

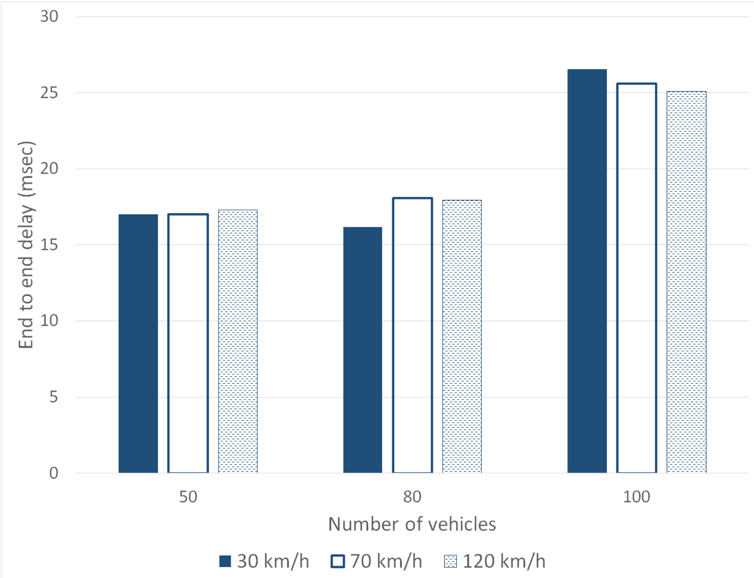

Figure 7.11: Average end to end delay as a function of vehicle density and speed.

7.6.3 Study the existing routing protocol

In this section, we compare system performance of different routing protocol named AODV, DSDV and AODV. Table 7.4 and Figures 7.13, 7.14, 7.15, 7.16, 7.17 and 7.18 obtained for AODV, DSDV and DSR protocols as a function of payload size while a network model of 80 vehicles with speed level 70 is used.

In figures 7.13, 7.14 and 7.15, we present the throughput behavior of model over simulation time for different routing protocol. 1 kilobyte to 10 kilobyte range of data payload is used. AODV and DSR protocol have zero throughput duration as mentioned previously as shown in figures 7.13 and 7.15. While DSDV show stable connections over the time as shown in figure 7.14. Nevertheless, DSDV shows low performance compared to AODV and DSR protocols in case of low throughput values and fluctuated behavior. On the other hand, obviously higher payload size increases the data throughput of system.

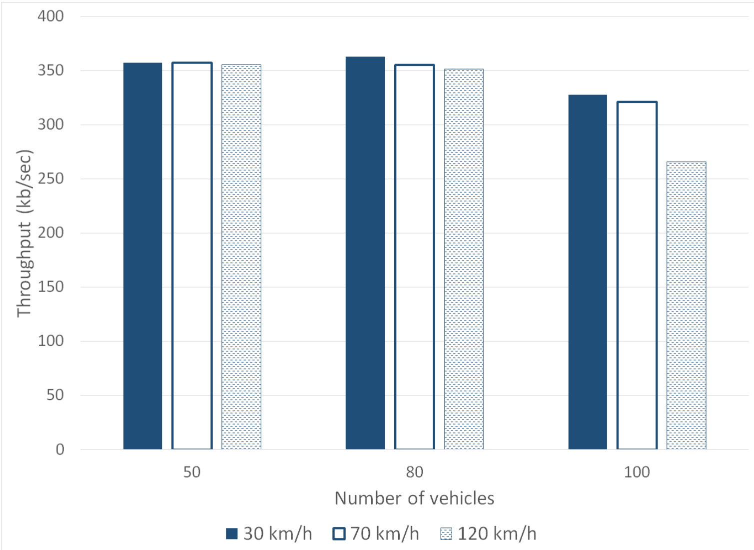

Figure 7.12: Average data throughput as a function of vehicle density and speed.

Figure 7.16 presents total number of dropped packets of AODV, DSDV and DSR protocols. Obviously, DSDV protocol has the quite highest number of dropped packets regardless of payload size. This make DSDV a low performance protocol for vehicular networks. On the other hand, DSR obtain lower number of dropped packets than AODV for all sizes of data payload due to their behaviors. Where DSR produces less discovery messages overhead than AODV. AODV tends to keep obtained route longer than DSR. But, vehicular networks are changeable over the time due to vehicle high movements and speed. Thus, valid routes get non valid routes in short time.

Figure 7.17 presents average end to end delay of AODV, DSDV and DSR protocols. The simulation results shows that as the size of data payload increase, the end to end delay increase for all protocols. DSDV protocol shows better performance in term of end to end delay than other protocols as a result of proactive behavior. Where, proactive behavior offers more chances for protocol to find routes

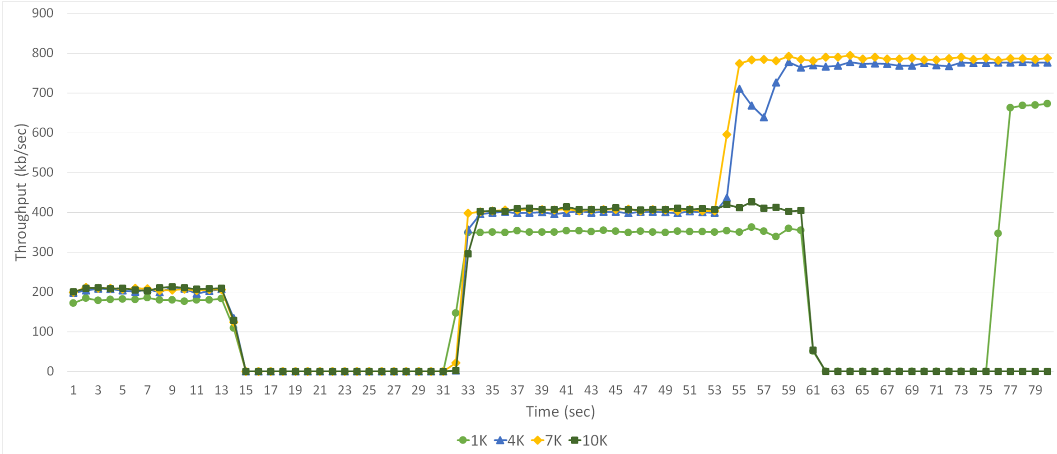

Figure 7.13: Data throughput for 80 vehicles, 70 km/h vehicle speed over AODV routing protocol with different data payload.

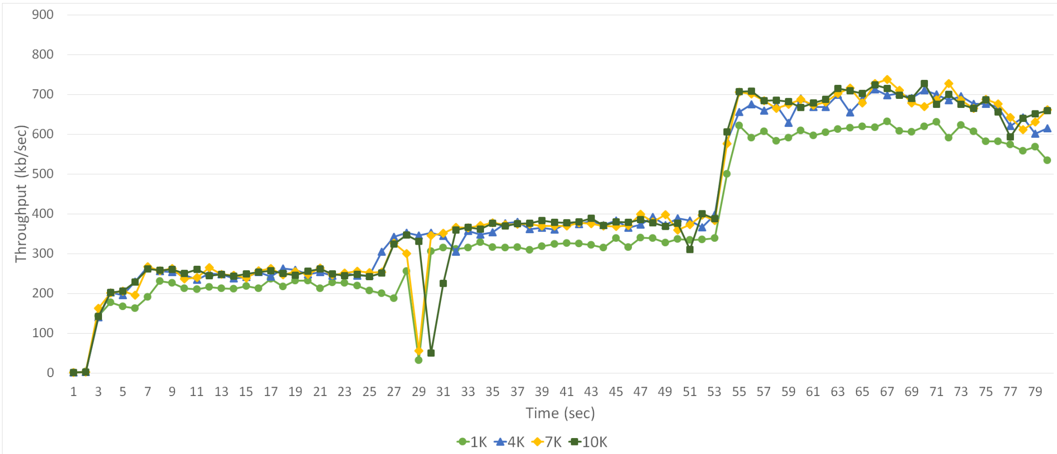

Figure 7.14: Data throughput for 80 vehicles, 70 km/h vehicle speed over DSDV routing protocol with different data payload.

but with high rate of packet drop and retransmissions due to heavy discovery messages overhead which cause high packet collision. For reactive protocols, high transmission delay is gained for DSR protocol due to route maintenance method. DSR protocol uses the cache intensively with a shortage of repairing broken links and expiring stale route cache information. Thus, AODV outperforms DSR in high mobility and unstable networks.

Table 7.4 and figure 7.18 presents the average data throughput AODV, DSDV

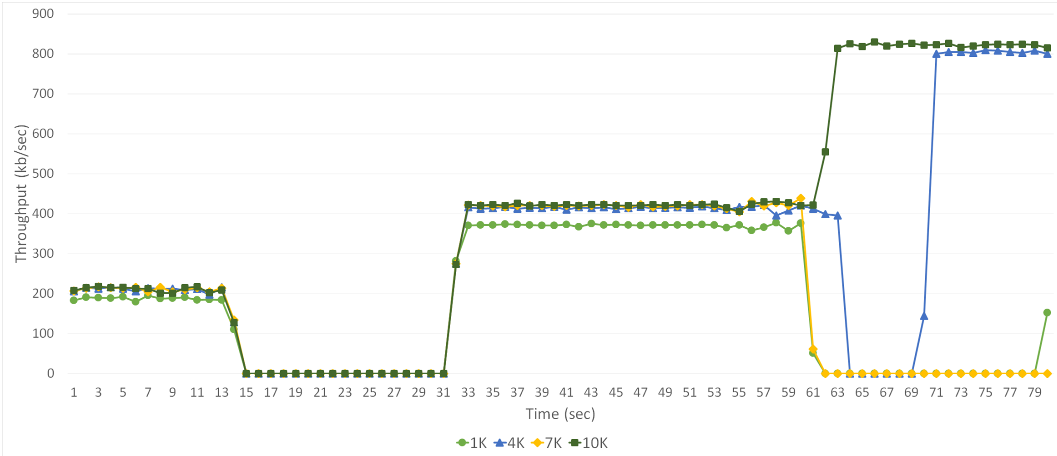

Figure 7.15: Data throughput for 80 vehicles, 70 km/h vehicle speed over DSR routing protocol with different data payload.

Table 7.4: Average Data Throughput as a function of Data Payload and Routing Protocol for 80 Vehicles and Speed Level 70.

Data Payload	1 kilobyte	4 kilobyte	7 kilobyte	10 kilobyte
AODV	355.0026	391.559	404.563575	405.119
DSDV	366.8351	421.61035	422.59185	421.45015
DSR	386.437625	445.624375	412.54155	490.478325

and DSR protocols as a function of payload size. The highest average throughput is 490.478 kb/sec of DSR protocol with 10 kilobytes data payload. And the lowest average throughput is for AODV protocol with 355.001 kb/sec with 1 kilobyte data payload. AODV shows lower performance compared to DSR and AODV protocols in case of average throughput for all sizes of data payload. However, DSR protocol performs better in most cases. Again, it is clear a higher payload size increases the data throughput of system.

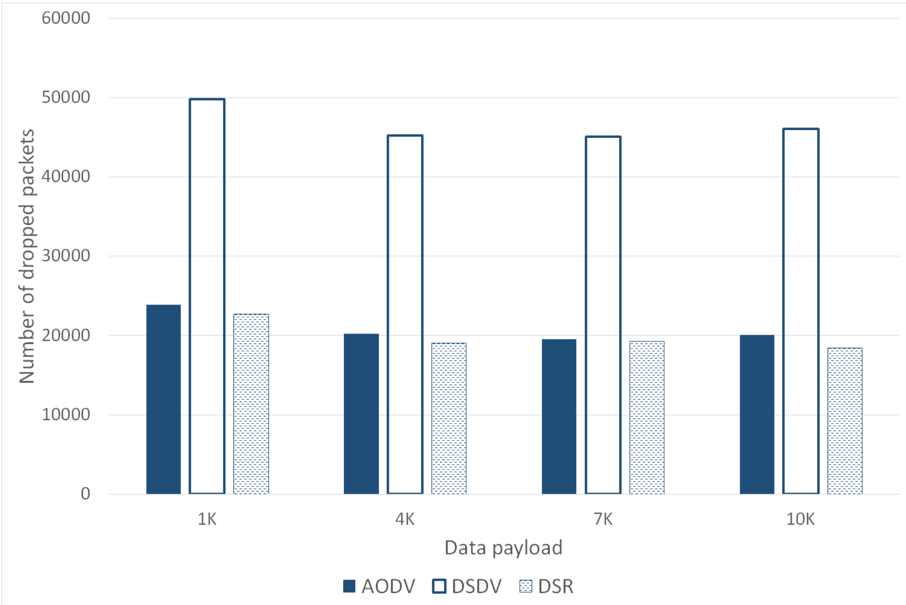

Figure 7.16: Total number of dropped packets comparison of routing protocols over different payload size.

7.6.4 General Observation

In this part, we will try to summarize simulation outcomes and give a general observation. In our simulation, we study the impact of integrating infrastructure in vehicular communication model. Then, we study the effect of increasing and decreasing the vehicle density and vehicle speed. Also, we compare performance among well-known ad hoc routing protocols and test them over different data payload.

Results in section 7.6.1 show that relying on infrastructure stations such as RSUs provide considerable advantage and improve the scalability and availability of different application in vehicular networks. Moreover, RSU nodes moderate connection disruption for data linked nodes in high mobility vehicular networks.

Several observations were made from results in sections 7.6.2 and 7.6.3. First,

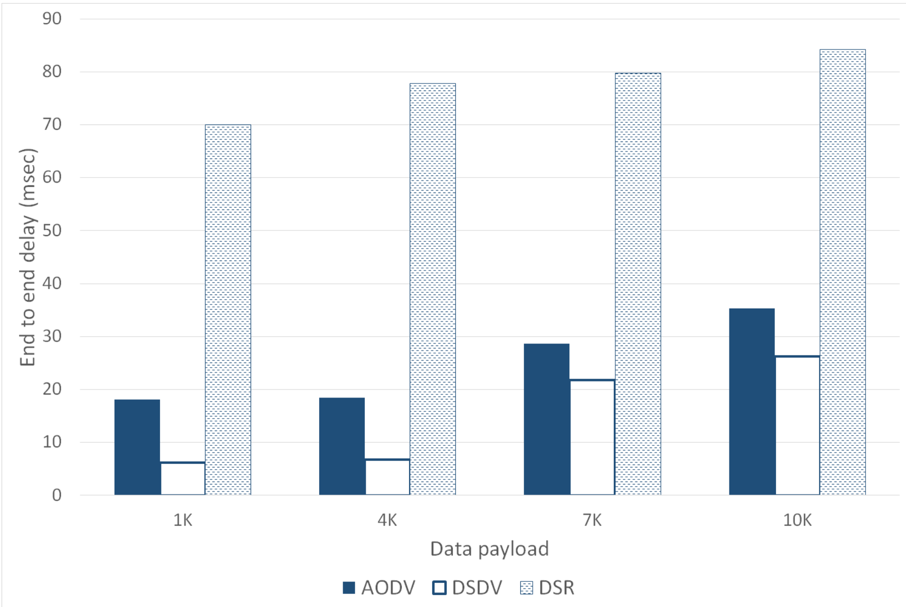

Figure 7.17: Average end to end delay comparison of routing protocols over different payload size.

the number of dropped packets and collisions increase with higher vehicle density. Second, throughput depends on routing protocol performance and it is increase with the increase of data payload size. Also, packet drop rate effect the system performance in case of throughput. Third, high vehicle speed level causes lower data throughput and higher packet drop. Finally, DSR shows higher performance compared to DSDV and AODV protocols where DSDV has the worst performance values.

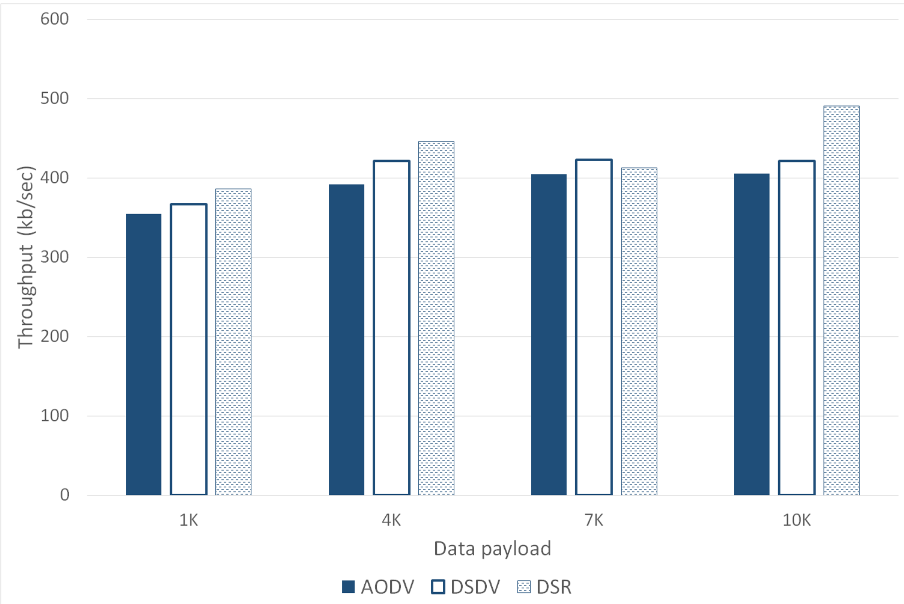

Figure 7.18: Average data throughput comparison of routing protocols over different payload size.

CHAPTER 8

CONCLUSION

E-Ambulance system is a smart ambulance model which provides auto response actions in addition of monitoring to increase the probability of saving patients from life-threatening conditions. Biosensors, Actuators, Intelligent unit, GPS and other components and technologies are used to achieve this mission. DDS model is used to provide connection between these heterogeneous elements of system. Furthermore, DDS middleware is effective to handle all aspects of real-time mission critical systems as E-Ambulance system where any failure in delivering patients status information will cost their life.

In our experimental work we measured performance of using DDS in our system. Thus, we evaluate latency, success ratio, and throughput performance metrics of wireless communication between certain numbers of nodes over different QoS profiles. In general, DDS show strong performance behaviour and satisfy medical requirements of delivering monitoring data under certain bounds. Moreover, we compare performance among four QoS profiles (default profile included) to get the most efficient QoS profile for medical environment. As future work, more parameters of QoS policies and RTPS protocol can be tuned to enhance the experience of DDS in medical systems over different wireless technologies such as WiFi, Bluetooth and ZigBee. Also, adding real-time conversational audio and video based teleconsultation to E-Ambulance platform may also be investigated.

In inter-ambulance communication part, we proposed a V2X communication model and built it over Makkah city scenario. Due to the difficulty to have comprehensive method for building vehicular based application scenario, we tested this model over several vehicular network parameters in NCTUns simulator environment. As an advantage of using NCTUns in simulation, a realistic map scenario, mobility model, topology and application stack is developed. However, vehicle density, vehicle speed, routing protocol, and data payload is the evaluated vehicular network configurations. In general, data throughput degrade with higher connection disruption, packets drop and collisions rates. Furthermore, high density and speed vehicular environment has higher packet drop rate. On the other hands in our simulation model, DSR and AODV show better performance than DSDV. Even though, DSDV shows lower connection disruption due to its routing behavior as a proactive protocol. Moreover, we study the effect of deploying infrastructure stations such as RSUs in our model whereas results show a positive impact of employing RSUs. As a future work, geographic based and destination based routing protocol should be implemented and tested over E-Ambulance vehicular model. Additionally, a real application scenario comprise intra and inter ambulance communications should be developed to evaluate the proposed platform.

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