SN Computer Science (2021) 2:232
https://doi.org/10.1007/s42979-021-00599-4

ORIGINAL RESEARCH

Cross Layer Design for Wi-Fi Sensor Network Handling Static and Dynamic Environment Using Local Automate Based Autonomic Network Architecture

K. N. Sanjay[1] · K. Shaila[1] · K. R. Venugopal[2]

Received: 10 November 2020 / Accepted: 18 March 2021 / Published online: 22 April 2021

Abstract

In social activities with shared Wi-Fi needs to accommodate large number of users and effectively handle congestion. These are critical issues due to the presence of larger density nodal activity at nearby access points involving inter-technology interference. An interference involves a statistical approach in monitoring access points with its received errors. The received errors vary with frame reception at their fields like PHY, MAC headers and payloads. Local automate-based Autonomic Network Architecture a cross layer approach algorithm is proposed to channelize a frame reception and can effectively avoid inter-technology interference. This results in P2P communication at initial stages and can accommodate multiple mobile devices with varying signal strengths. The algorithm is deployed for a dynamic environment along with static clusters. The throughput of the entire network is increased by 20% because of identifying multiple nodes with lesser latency avoiding congestion.

Keywords Autonomic network architecture · Local automate · Medium access control layer · Physical layer · Point to point (P2P) · Wireless fidelity (Wi-Fi) · Wireless sensor network

Introduction

The deployment and its popularity of Wireless Sensor Network provides users to think beyond its timeliness. The classification of WSN starts from few meters to several kilometers. With higher distance coverage Wireless Fidelity(Wi-Fi) is among the one with good reliability features in practical applications. Wi-Fi operating rages from 900MHz, 2.4 GHz, 3.6 GHz, 4.9 GHz, 5 GHz, 5.9 GHz and 60 GHz bands. The 2.4 GHz is considered as it can be found in most of the industrial applications handling a larger density of nodes. The process looks simple if the area is not set as a constraint in using Wi-Fi. The collision and congestion can be easily avoided with larger space and high bandwidth compared to UWB, Bluetooth or even ZigBee [1–5].

The sensor network data with large density nodes in a smaller area with lesser collisions and congestion is considered. The use of Wi-Fi includes both static and dynamic environments. While in a smaller network including 5–15 nodes can be made dynamic. One such example is Wi-Fi Hot-spot using cellular phones. While with industrial applications are concerned it involves Wi-Fi stations with routers and larger number of nodes in a wide spread environment. The support by each level of design in a combined static and dynamic environment if fulfilled at a certain level based on strength of a signal and receiving nodes capability.

The data transfer rate differs from node to station level. Capturing the various strengthen in signal and transmitting at a required data rate requires user attention. To fill this gap between a various data rate operation a local automate based autonomic network architecture is proposed [6]. Local automate chooses nodes, routers based on their probability of occurrence.

The architecture provides modeling information and processing is task driven with the collaborative neighborhood.

This article is part of the topical collection "Cyber Security and Privacy in Communication Networks" guest edited by Rajiv Misra, R K Shyamsunder, Alexiei Dingli, Natalie Denk, Omer Rana, Alexander Pfeiffer, Ashok Patel and Nishtha Kesswani.

✉ K. N. Sanjay
sanjaykenkare@gmail.com

1 Department of Electronics and Communication Engineering, Vivekananda Institute of Technology, Bangalore, India

2 Bangalore University, Bangalore, India

The complete architecture is Self-Optimized, protective, configurable and healing. The semantic routing considers a shortest path algorithm in routing packets from source to destination with corresponding active node [7–10].

Wireless Sensor Networks with localization for Wi-Fi is an active research area that involves various challenges with multiple benchmarks need to be resolved. This includes competitive analysis at an initial stage and further involves navigation schemes that affects performance. In most scenarios D2D (device to device) communication is preferred with short-range that includes: lower band, greater throughput and improved energy efficiency [11, 12]. A set of application are defined by IEEE 802.11 enabling the PHY and MAC layer to support WLAN communication. The software required in 802.11 MAC layer specify the behavior of communication that supports the physical layer. This involves data delivery, access control and security as discussed in [13].

The process of Local automate always provides information of probability of occurrence of any event with a pre-defined environment. In LA, the initial stage of Wi-Fi process enables user for complete competitive analysis for determining the probability of occurrence of each node. This leads in decisive dead spots that avoids slow and unstable connections [14–16]. The inter-interference region can cause decrease in deployment efficiency with more IT investment.

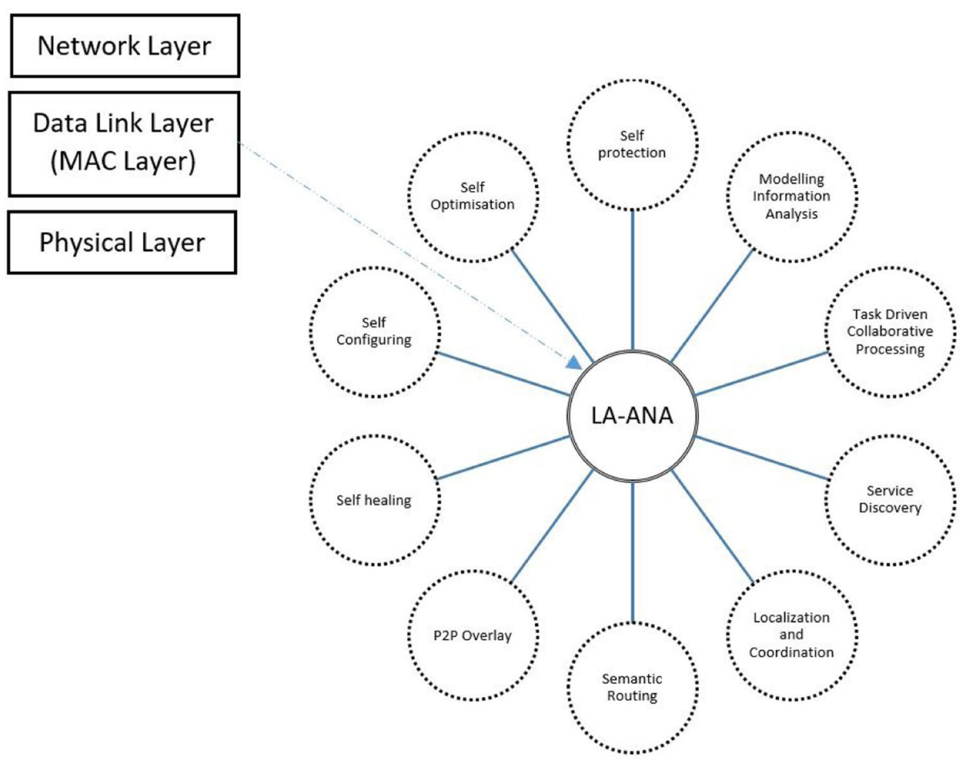
The Autonomic Network Architecture with address agnostic feature could be a part of the MAC layer in addressing said issue. Proper channelization would be a feasible solution at the next phase of the design [17–19]. The complete architecture is shown in Fig. 1. The MAC layer includes a LA-ANA architecture that supports the following features:

(a) Self-protection, Self-Optimization, Self-Configuring, Self-healing leads to adaptively deploy a network in predefined environment
(b) Service discovery, localization and Coordination with Semantic routing provides a local automate process with improved routing and neighborhood.
(c) Modeling Information Analysis and Task Driven Collaborative Processing involves nodes that are active and when the node fails, it helps in utilizing neighbor nodes effectively for communication.

Motivation The propagation of the signal in a tangled indoor environment with multiple paths are always obstructed by objects. Few of the examples are: walls, people, doors, furniture and many more. This leads to dead spots and requires increased strength in signal. Thus, designing a MAC protocols involving efficient bandwidth usage is our primary concern.

While designing a system comprising of larger density nodes with congestion requires efficient use of bandwidth which can be achieved by multipath transmission. This results in lesser throughput as fault tolerance level increases

Fig. 1 Architecture of ANA in data link layer



due to multi-path interference. Hence, designing Wi-Fi environment handling both static and dynamic density environment at larger density requires user concern at slower and unstable connections.

Contibution The combined environment of static and dynamic scenarios is designed using cross-layer design. The occurrence of each node either in the static or dynamic region is determined using Local Automate. This is followed by address agnostic feature of an Autonomic Network Architecture. Thus, handling both static and dynamic nodes is feasible with higher fidelity utilizing the entire bandwidth allocated.

Organization Section "Literature Survey" presents a Literature Survey followed with problem definition in Sect. "Problem Definition". Section "System and Mathematical Model" briefly explains system and mathematical model with the necessary set of equations. Section "Implementation" discusses the LA-ANA based implementation in Wi-Fi with relevant algorithms. Simulation and performance evaluation of dynamic and static environment are briefly explained in Sect. "Simulation and Performance Evaluation" and conclusions in Sect. "Conclusions".

Literature Survey

Reliability of the network with latency is address in [1] using un-slotted 802.15.4 network resulting in handling large sensor nodes. The trade-off with delay will be uncertain and can result in un-slotted array of regions leading to congestion within smaller area.

The network need to be made smart and should consider blind learning increasing probability of occurrence as discussed in [2]. Thus, performance with frame concentration can be increased leading to new opportunities with routing leading to lesser collision and energy consumption [3–5].

The interference region of the network need to be considered while addressing that enables crowd-sensing localization. This results in cost-effective design while for full-duplex transmission modeling and analysis would become difficult. Thus cross-layer approach with wi-Fi probes could be a compact beacon model in solving the issue [6–10].

Khan et al. [11] discussed Wi-Fi signals have extensive application in collapsed structures that involves various challenges of Wi-Fi technology like dead spots, bandwidth related and more. The problem persists with coexistence scenarios involving the dense network. The spectrum sharing in dense network with low cost includes some of the FEM applications [12, 13].

The process of handling signal to image in Wi-Fi enables users to think with uni-cast and multi-cast delivery rates with transceiver integration. This helps in improved throughput with lower energy consumption. The formation of the network with said delivery rates causes congestion at a large denser network in a dynamic environment [14, 15]. Li et al. [16] had carried out a case study on performance evaluation for Wi-Fi sniffing that support optimal groups. Further, Khan et al. [17] proposed an Optimal Group Formation with content distribution for the entire direct network comprising of large nodes. It avoids congestion and increases overall throughput.

With increased data rate and Wi-Fi, localization can be implemented using convolution neural networks. This involves calculations resulting latency [18]. Lu et al. [19] proposed Autonomous learning capability with noisy sensor data, which can be used as a Geofence. Geofence is one of the application enabling user to consider local automate based Autonomic Network Architecture.

Problem Definition

Problem Statement The congestion in the transmission is due to large number of nodes in a smaller area. The switching of static and dynamic environment also leads to data collision. This provides unsucessful implementation for uni-cast and multi-cast delivery in Wi-Fi dynamic environment.

objective of our work is to

(i) Increasing activity-based address agnostic for a dynamic environment based on static inputs.
(ii) With interference region based on the activity of node assigning the nearby router based on autonomicity.
(iii) Avoiding congestion while switching and increased throughput with increased tolerance fault levels in a denser network.

Assumptions In building an entire network model following are few of our assumptions

(i) Initial process starts with Local Automate combined with Address Agnostic of ANA architecture.
(ii) Switching between static and dynamic environments based on the probability of occurrence of each environment nodes.
(iii) Selection of shortest path with Active and Sleep nodes based upon address agnostic feature.
(iv) With higher fault tolerance levels selected dead spots chosen are minimal

System and Mathematical Model

Local Automate-based Autonomic Network Architecture with trouble-free network is implemented at MAC layer of Wi-Fi. The layer deployed is available at data link layer of the network protocol without disturbing actual properties of WSNs. The system architecture comprises of calculations on probability and address agnostic feature of LA and ANA respectively. The probability of occurrence of each and every node in dynamic path helps user to regulate back trace in finding shortest route in case of nodes failure. This helps in adaptive rerouting while switching between static and dynamic environments. The said architecture is implemented at lower layer of Network Layer called MAC layer.

The local automate finds probability and further address agnostic feature is deployed on top of LA resulting in LA-ANA-based architecture. The combined cross-layer design helps user to switch between static and dynamic environments with changing addresses of nodes. This is made possible using address aganostic feature that pretends to minimize overall interference region of the network. Thus, supporting for addressing faulty nodes in a pre-defined regions. This addresses fault nodes with uni-cast and multi-cast deliveries with minimal latency. Thus, avoiding congestion and improving tolerance levels with fault occurrence resulting in higher throughput. The uni-cast and multi-cast deliveries can be deployed with minimal latency.

Mathematical Model

Let '*n*' be the number of nodes in a dynamic environment with 'm' static routers. The probability of occurrence of each active node would be an interval estimation of model and is given by

$$P_{m|n}\left[p_{(1)}, p_{(2)}, \ldots, p_{(i)}, \ldots p_{(n+1)} \mid P_{m1}\right] \tag{1}$$

where, P_{m1} refers to static network '*m1*' in a predefined environment.

$p_{(n+1)}$ refers to a particular dynamic node in a static environment with a probability of its occurrence.

The error predicted in each node and its neighboring dependability is a difference between *i*th and *j*th node and is computed as

$$\begin{aligned} e_{m1|i} = \Big| &\left[p_{(i1)}, p_{(i2)}, \ldots, p_{(ii)} \mid P_{m1}\right] \\ &- \left[p_{(j1)}, p_{(j2)}, \ldots, p_{(ji)} \mid P_{m1}\right] \Big| \end{aligned} \tag{2}$$

The combination of present probability of occurrence and error with neighborhood always provides state of each node i.e.., either active or sleep or failure. The intermediate nodes that switch between any numbers of the static router that are dynamic can be easily routed using expressions (1) and (2). Thus, LA-ANA based environment can be created while handling larger packets in a reciprocated environments.

Implementation

Wi-Fi environment with 20-30 sensor nodes and 4 routers are considered in implementing LA-ANA based architecture as shown in Fig. 2 for illustration.While entire network is varied with 100–1000 nodes and with more than 50 routers during simulation. The network is made denser to estimate the probability of occurrence of each node. The randomness is considered and is shown in Fig. 3 for interference region. The user can wish and select manually to any of Router environment.

The proposed architecture provides uni-cast and multi-cast delivery. If any one of interference region node fails then based on probability of occurrence, nodes select either of the routers. This is made possible based on address agnostic feature deployed at MAC layer of the network and can switch between 2 Routers pertaining with higher signal strength and capability. The process may look simple while addressing of routers within a smaller region requires LA-ANA based architecture. The routers are always fixed at one position and is made static. The sensor nodes may vary with density and is dynamic.

The proposed algorithm with Local Automate and Autonomic Network Architecture is described in Algorithms 1 and 2.

The probability of occurrence of each node in a path is provided as an input followed by ANA. The static or dynamic environment is considered based on the activity occurred at Steps 3, 4 and 5 of Algorithm 1. The ANA is considered for a static environment with generic nodes. The nodal activity estimation is carried out and are updated with any disturbances that occurs during transmission. The updated information of Algorithm 2 is validated in Algorithm 1. The process continues until successful transmission of packets from source node to destination node in a predefined arbitrary path.

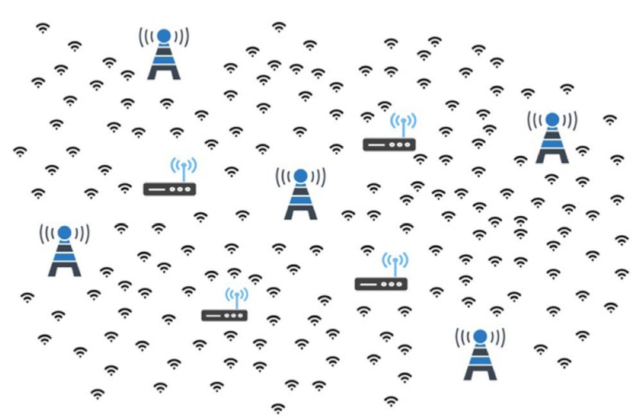


Fig. 2 Wi-Fi sensors and routers of around 10–30 and 4 respectively

Fig. 3 Wi-Fi environment with routers and nodes

Algorithm 1: LA-ANA for Wi-Fi with probability estimation.

Step 1: Consider AODV Environment with initial parameters
Step 2: Intermediate Nodes with multiple clusters are chosen
Step 3: Find probability of occurrence of dynamic nodes and static clusters
Step 4: Estimate total distance number with selected path
Step 5: Packets will be send in either uni-cast/multi-cast mode
Step 6: Call environment response with LA-ANA()
Step 7: Update resulting probabilities from LA-ANA()
Step 8: In case of failure at dynamic nodes or static clusters then re-initiate and re-transmit packets from step 5
Step 9: Procedure continues until delivery of packets comes to an end

Algorithm 2: ANA for Wi-Fi.

Step 1: Generic nodes with static cluster are considered
Step 2: Check for minimal probabilistic nodes
Step 3: Update estimation of nodal activity
Step 4: Autonomicity of cluster address updates are also considered
Step 5: Return the values of multiple path with static cluster and dynamic nodes selected

The AODV environment refers to hop communication range that supports multi-hop transmission between multiple transceivers. The algorithm determines the required probability of occurrence of each node based on neighborhood. The process is repeated until successful transmission is observed between intermediate nodes.

Figure 4 shows the timing diagram for Wi-Environment. For instance we consider source and destination nodes along with 2 intermediate nodes I_1 and I_2. During failure of nodes, I_i and I_j are consider for successfull transmission. Successfull transmission along with Re-transmission of packets with acknowledgement received is as also shown in Fig. 4.

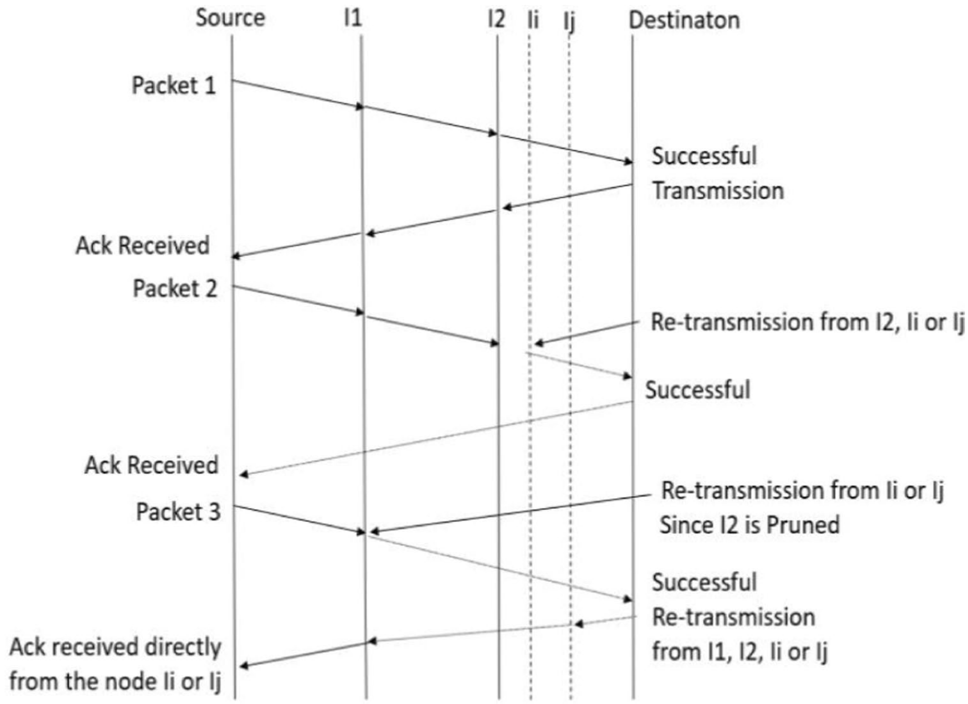


Fig. 4 Packets transmission between active and sleep nodes

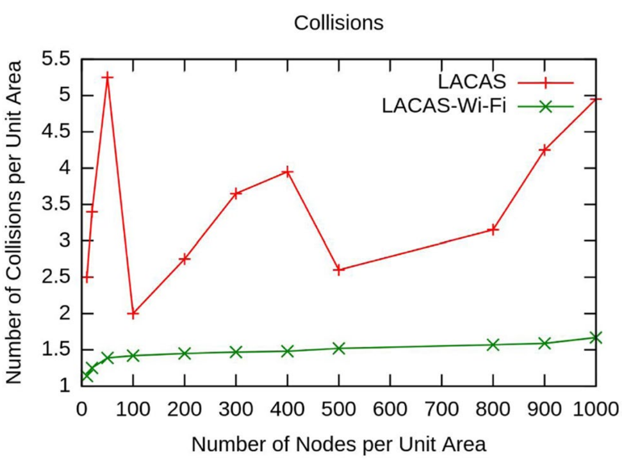


Fig. 5 Collisions in Wi-Fi

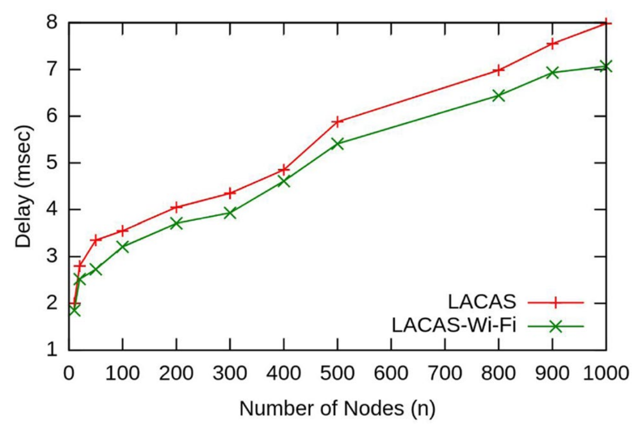


Fig. 6 Congestion in Wi-Fi

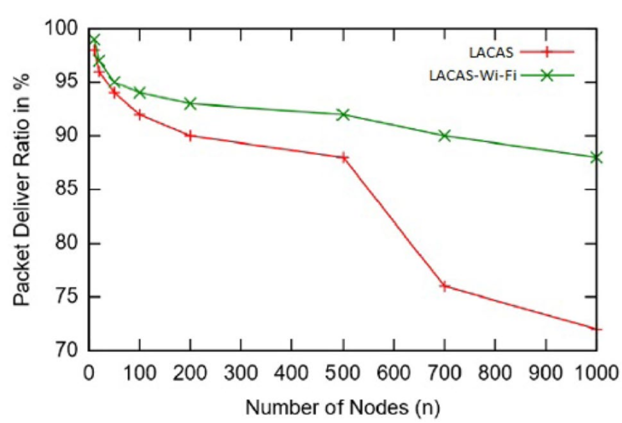


Fig. 7 Packet delivery ratio

Simulation and Performance Evaluation

Simulation Environment

The operating band of Wi-Fi is 2.4 GHz and can reach up to 150 feet in an indoor environment. It can reach up to 300 feet in an outdoor environment. While 802.11a older bands were operating at 5 GHz and their corresponding distance were limited to 1/3rd of range provided both in indoor and outdoor environments. Since operating range is higher and available power density is sufficient for planned multi-cast delivery.

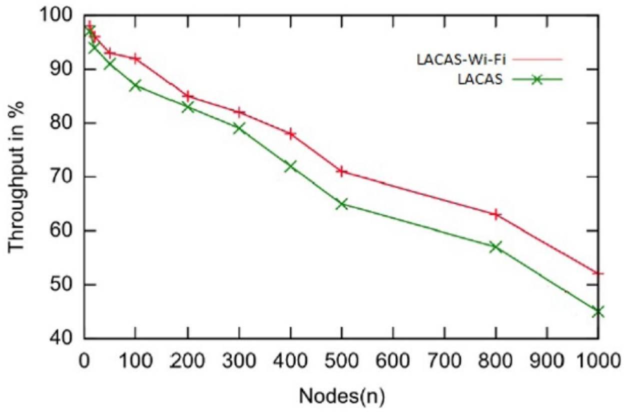


Fig. 8 Throughput

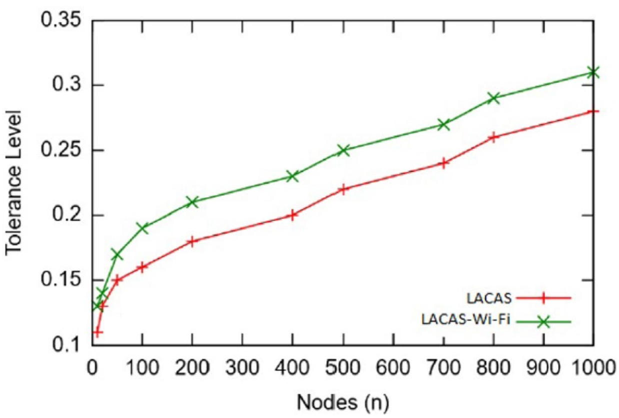


Fig. 9 Fault tolerance levels

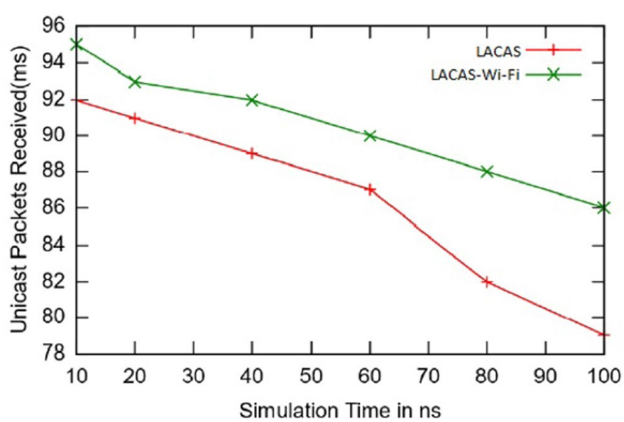


Fig. 10 Uni-cast delivery

For incorporating path loss around 5 (constant) is chosen for phase 2 in random. NS2 Simulation Environment with 50 ms of Simulation time is built considering SNR bound reception. The Noise Figure is around 10.0 with Radio Acoustic Noise as a standard radio model considering

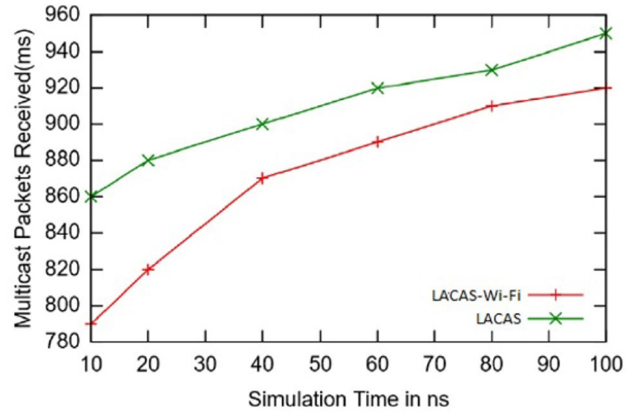


Fig. 11 Multi-cast delivery

a random Node placement. The MAC layer of Data Link Layer is considered with power transmission of 20 dBm. The smaller area of 1 km diameter is considered during the entire process in both static and dynamic environment.

Performance Analysis

The collision in network is normalized with an increased in number of node density as shown in Fig. 5. Collision had not exceed more than 2% with a large number of nodes in a smaller area. Congestion in the network is reduced around 1.8 ms of delay with lesser number of nodes and around 2 ms at larger density nodes is shown in Fig. 6.

The reduction in congestion and collision has improved packet delivery ratio with LA-ANA by 25% and not letting to reach below 90% with a large number of nodes in a smaller area and is as shown in Fig. 7.

The decrease in Collision rate is due to local automate wherein probability of each node occurrence is determined based on neighborhood. This helps in making neighborhood active resulting in higher throughput as shown in Fig. 8. Thus, resulting in increase of tolerance level for each node as shown in Fig. 9.

The fault tolerance levels are increased at higher density is due to neighborhood and address agnostic feature of ANA architecture. Fault tolerance levels are increased using the LA-ANA architecture with 2% at lesser number of nodes and there is 6% substantial increase at higher density of nodes in a dynamic environment.

The address agnostic feature in ANA helps user to implement uni-cast and multi-cast delivery with sufficient improvements as shown in Figs. 10 and 11 respectively. The uni-cast delivery is more effective in routing dynamic environment and multi-cast in static environment avoiding inference regions.

The combined LA-ANA provides a feasible stability in handling uni-cast and multi-cast deliveries with active

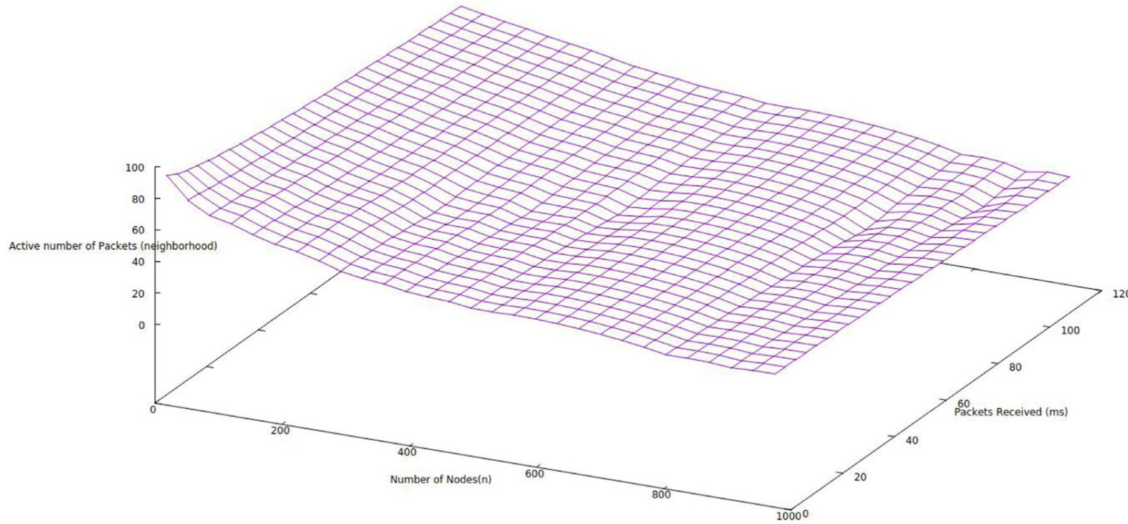


Fig. 12 Uni-cast delivery with active regions

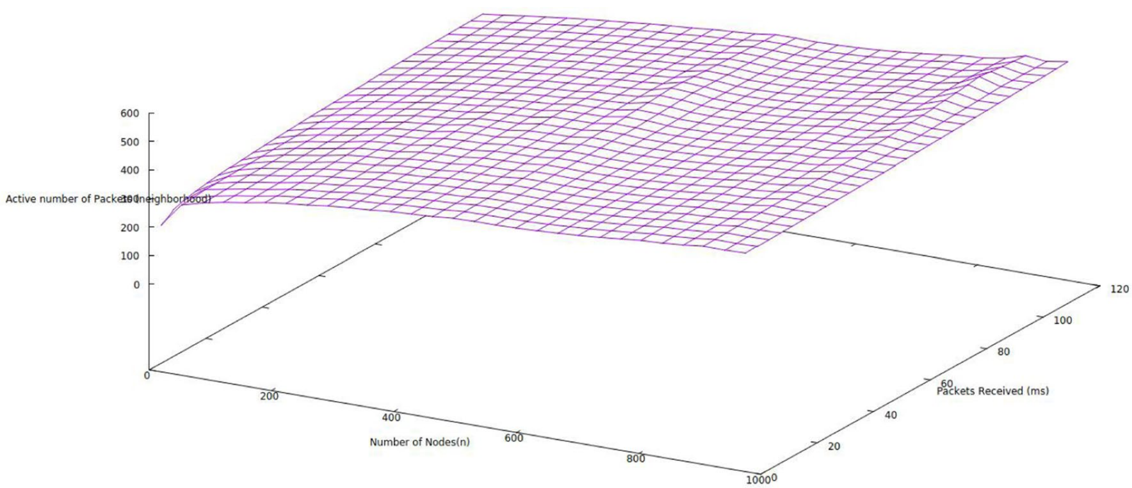


Fig. 13 Multi-cast delivery with active regions

number of nodes varying with its neighborhood is shown in Figs. 12 and 13 respectively. The variation in active number of packets with packets received in msec is shown with increased number of nodes in Figs. 12 and 13.

Conclusions

The LA-ANA-based architecture for a Wi-Fi in handling both static and dynamic environment is implemented and is feasible with good fidelity. The LA-ANA based architecture is a new design criteria for a Wi-Fi environment (static and dynamic) that is capable of handling both sensors and routers effectively. This provides uni-cast and multi-cast deliveries as it can successfully handle interference region created with '*m*' number of routers. Thus, LA-ANA architecture provides an improved switching action between routers and nodes with increased throughput and lesser collision improving fault tolerance levels.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Zeng X, Liu K, Ma J, Chen M, Yu M. Reliability and delay trade-off analysis of unslotted IEEE 802.15.4 sensor network for shipboard environment. IEEE Sens J. 2021;21(2):2400–11.
2. Nguyen TT, Oh H. SCSMA: a smart CSMA/CA using blind learning for wireless sensor networks. IEEE Trans Ind Electron. 2020;67(12):10981–8.
3. Barroca N, Velez FJ, Borges LM, Chatzimisios P. Performance enhancement of IEEE 802.15.4 by employing RTS/CTS and frame concatenation. IET Wirel Sens Syst. 2020;10(6):308–19.
4. Kumar Shah I, Maity T, Singh Dohare Y. Algorithm for energy consumption minimisation in wireless sensor network. IET Commun. 2020;14(8):1301–10.
5. Deng C, et al. IEEE 802.11be Wi-Fi 7: new challenges and opportunities. IEEE Commun Surv Tutor. 2020;22(4):2136–66.
6. Garrido-Valenzuela F, Raveau S, Herrera JC. Bayesian route choice inference to address missed bluetooth detections. In: IEEE Transactions on Intelligent Transportation Systems; 2020. pp. 1–10.
7. Yang G, Shi X, Feng L, He S, Shi Z, Chen J. CEDAR: a cost-effective crowdsensing system for detecting and localizing drones. IEEE Trans Mob Comput. 2020;19(9):2028–43.
8. Cao X, Song Z, Yang B, Qian L, Han Z. Full-Duplex MAC in LAA/ Wi-Fi coexistence networks: design, modeling, and analysis. IEEE Trans Wirel Commun. 2020;19(8):5531–46.
9. Biswas S, Roy SD, Chandra A. Cross-layer energy model for non-beacon-enabled IEEE 802.15.4 networks. IEEE Wirel Commun Lett. 2020;9(7):1084–8.
10. Tang X, Xiao B, Li K. Indoor crowd density estimation through mobile smartphone Wi-Fi probes. IEEE Trans Syst Man Cybern Syst. 2020;50(7):2638–49.
11. Khan M, Wang G, Bhuiyan M, Yang K. Toward Wi-Fi hallow signal coverage modeling in collapsed structures. IEEE Internet J. 2020;7(3):2181–96.
12. Dziedzic A, Sathya V, Rochman M, Ghosh M, Krishnan S. Machine learning enabled spectrum sharing in dense LTE-U/ Wi-Fi coexistence scenarios. IEEE Open J Vehicul Technol. 2020;1(1):173–89.
13. Chiu J, Hsiao S, Tseng P, Lai Y, Huang C. An ultra compact, low-cost, and high-performance rf package technique for Wi-Fi FEM Applications. IEEE Microw Wirel Comp Lett. 2020;30(3):265–7.
14. Guo L, Lu Z, Wen X, Zhou S, Han Z. From signal to image: capturing fine-grained human poses with commodity Wi-Fi. IEEE Commun Lett. 2020;24(4):802–6.
15. Liu R, Asma KT, Dorrance R, Dasalukunte D, Kristem V, Santana Lopez M, Min A, Azizi S, Park M, Carlton B. An 802.11ba-based wake-up radio receiver with Wi-Fi transceiver integration. IEEE J Solid State Circuits. 2020;55(5):1151–64.
16. Li Y, Barthelemy J, Sun S, Perez P, Moran B. A case study of Wi-Fi sniffing performance evaluation. IEEE Access. 2020;8(1):129224–35.
17. Khan M, Hamila R, Hasna M. Optimal group formation in dense Wi-Fi direct net-works for content distribution. IEEE Access. 2019;7(1):161231–45.
18. Bocanegra C, Kennouche T, Li Z, Favalli L, Felice M, Chowdhury K. E-Fi: evasive Wi-Fi measures for surviving LTE within 5 GHz unlicensed band. IEEE Trans Mob Comput. 2019;18(4):830–44.
19. Lu C, Xiangli Y, Zhao P, Chen C, Trigoni N, Markham A. Autonomous learning of speaker identity and Wi-Fi geofence from noisy sensor data. IEEE Internet Things J. 2019;6(5):8284–95.