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The Role of Ad Hoc Networks in Mobile Telecommunication

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1. Introduction

The installation, improvement, maintenance and operation of telecommunication networks are hampered by the ever changing trends in technology. The nature and design of existing telecommunication networks makes it difficult to integrate different segments, created by technological difference and fragments of various network operators and manufacturers. In addition to the enormous bandwidth and quality of service demands of telecommunications network users, they desire to ensure the availability of all the services and resources. Moreover, the users anticipate the availability of information services whenever or wherever they need it, while at the same time, satisfying temporal and spatial diversity considerations. In the midst of this ongoing progress in technology and continuing effort to integrate network resources from different providers, the ad hoc networks paradigm, with its unique benefits, is capable of easing the integration process and providing seamless access to information resources and connectivity in many practical scenarios (Remondo & Niemegeers, 2003). The ad hoc networks are self organizing networks and any kind of central management is not an essential requirement. In contrast to other prevailing telecommunication networks which support mobility, the case of ad hoc networks management is different and no stringent predefined infrastructure is critical to the establishment and operation of these networks. While the implementation of ad hoc networks seems to be simple at a first glance with apparent advantages in specific situations over existing mobile networks, there are significant challenges which inhibit the attachment and use in an integrated environment with existing mobile telecommunication networks (Freedman, 2009).

In this chapter, we discuss the role of ad hoc networks in mobile telecommunications. The trends in mobility are discussed with respect to the technological aspect, that is, from physical layer to application layer and social aspects which inherently influence the telecommunication network design and direct the future development trends in technology and its usage.

The existing network technologies and implementations are striving hard to accommodate the needs of users which indirectly govern the core design, life cycle, accessibility and

integration, this also include person to person interaction, video on demand or streaming contents, music, pictures, gaming, information, and business applications (Wang et al., 2008). Many of these applications require providing content at a mobile location, which to some extent is covered by traditional telecommunication networks, nevertheless to take the accessibility to the limit, the ad hoc networks can play a vital role in providing connectivity and advance services, especially where last mile is very critical and difficult to manage. Another important aspect in providing the users the facility to access the information from various resources and multiple formats is the design and specifications of the end devices. These end devices are evolving rapidly and are capable of integrating ad hoc network protocols and technologies to make them compatible with existing networks and future generation of ad hoc network systems. For example, many smart phones and notebooks have access to ad hoc networks and to some extent, are capable of integrating various mobile ad hoc network versions. In some instances where the users are mobile in remote areas which lack access to telecommunication networks, the ad hoc networks or more precisely the mesh networks can provide connectivity and availability of vital network resources, which in situations like disaster areas, battle fields, conventions, and remote areas can be very useful. The inherent underlying advantages of mobile ad hoc networks can further be exploited in situations where we require mobile multimedia, fixed to mobile convergence, voice over Internet protocol mobile applications, and network technologies with short life cycle risk (Cricelli et al., 2011). The fragmentation in the already established networks can be overcome by using ad hoc networks as bridges. The ad hoc network in this case provides interfaces to different technologies while connecting different mobile telecommunication networks via virtual connections and in some cases virtual network backbones.

In this chapter, we also present the advantages, disadvantages, and consequences of ad hoc networks when integrated with prevailing and future mobile telecommunication networks. Traditionally, a telecommunication network is governed and operated by an entity. The services provided by these entities generate revenue and there is no concept of decentralized management as far as revenue is concerned or providing services which are free of cost. The risk of ad hoc networks being used by masses in situations where the cost to use a service is very competitive or even free, poses a great risk for existing telecommunication operators. We discuss the implications of these types of scenarios in the prospective of mobile telecommunications and its influence on users (Akyildiz et al., 2005).

The ad hoc networks are capable of adapting rapidly, therefore, in situations where behavior of different types of users such as entrepreneurs, students, pensioners, singles, families, is observed simultaneously, especially when they are mobile and use different type of technologies and request connectivity, the traditional mobile networks lack acceptability and in many occasions become too costly. We provide an insight into the research progress pertaining to ad hoc networks which show a promising future to amalgamate in existing technologies and systems (Zhao & Liang, 2010). In a struggle to cut the prices to levels which are not even imaginable by existing subscribers and users, the role of ad hoc networks is also presented, and methods and ways are discussed related to cost management (Hac, 2002).

In recent years, the Voice over Internet Protocol (VoIP) has played a vital role in the evolution, development, and regulation of mobile telecommunication networks (Chang et al., 2009). The VoIP platform eases the integration process and provides a standardized protocol stack for telecommunication equipment vendors and system designers. In this

chapter, we focus on the progress of ad hoc network and their compliance to VoIP applications, the benefits provided by the use of VoIP acceptability at all levels and the reduction in complexity in the integration process with future mobile telecommunication networks. We also discuss the technological aspects which exist at each layer in open systems interconnectivity layered mode (Smith, 2006). The medium access layer, network layer, transport layer, and session layer are emphasized because of their important role in the governance, management and integration of these networks.

With the diminishing number of available channels in radio spectrum, it is vital that the use of available recourses should be in an efficient manner. The use of cognitive radios in conjunction with ad hoc networks has shown substantial improvements in bandwidth utilization (Comeras et al., 2007). We also present the use of such technologies and their implications on the performance enhancement in light of mobile telecommunications networks and ad hoc networks. In addition, the new technologies and systems are vulnerable to hackers and sometimes are less secure (Kaosar & Sheltami, 2009). We also discuss the issues related to security in the ad hoc networks with emphasis on mobility and integration with existing networks (Bayer et al., 2010).

With the advent of modern technology, everyone desires to stay connected, everywhere, all the time. The ever increasing demand for keeping in touch with the outside world has not only triggered a never ending technological development, but is also affecting the social life of an ordinary person in various ways. Telephonic conversation is no longer the only requirement for telecommunication users, now they like to play interactive games, share videos and files, browse the Internet, use social networking sites, check emails, hold video conferences and use other multimedia applications. Moreover, the users own more than one communication device and there is a requirement for interconnectivity.

In a typical cellular system, each node (cell phone) completes its communication with the help of a base station which is the control authority. The base station manages the network in combination with the Mobile Switching Station (MSC) which is connected to a Public Switching Telephone Network (PSTN). The demand for maximum connectivity requires the cellular network to install greater number of base stations. The problem arises when expanding the infrastructure is not possible or is expensive. Moreover, in battle fields or during natural disasters, the infrastructure is disabled or destroyed. During these times, the need for connectivity also increases as communication becomes more crucial in emergency situations.

2. Ad hoc networks

Ad hoc networks were first employed in 1970s, when US Defense Advanced Research Projects Agency (DARPA) installed packet radio network. The past couple of decades have seen a huge progress in the field of ad hoc networking. With the introduction of Bluetooth in 1998, a proprietary open wireless technology standard for exchanging data over short distances, ad hoc networks were used in commercial applications with eight devices in a small network, called the piconet. Ad hoc networks are autonomous networks which are not managed or controlled by a centralized infrastructure. The nodes in ad hoc networks are responsible for establishing communication links as requested by source nodes. The participating nodes act as routers, gateways, and as transmitters or receivers. Moreover, these nodes are mobile which makes the topology of the network dynamic. The ad hoc networks are spontaneously formed with the minimal assistance of communication

hardware infrastructure; therefore, these types of networks are suitable for emergency situations.

Ad hoc networks can be deployed in a wide range of applications such as, disaster relief areas, networks at construction sites and other temporary installations, vehicular networks, connecting organizations and hospitals, home and office networks, conventions, networks for users at airports and shopping malls. The key advantage of ad hoc networks is that they can be employed in any technology and integrated with all kinds of environments due to their dynamic and flexible nature. Ad hoc networks can be connected to pre-existing technologies like cellular and access hosts which are not part of ad hoc system. The use of ad hoc networks in combination with the existing cellular network can not only improve the performance and services of existing cellular network but can also provide connectivity in areas where cellular network is not available or not feasible. Some of the advantages of ad hoc networks include independence, flexibility, low cost, self healing and zero set up cost.

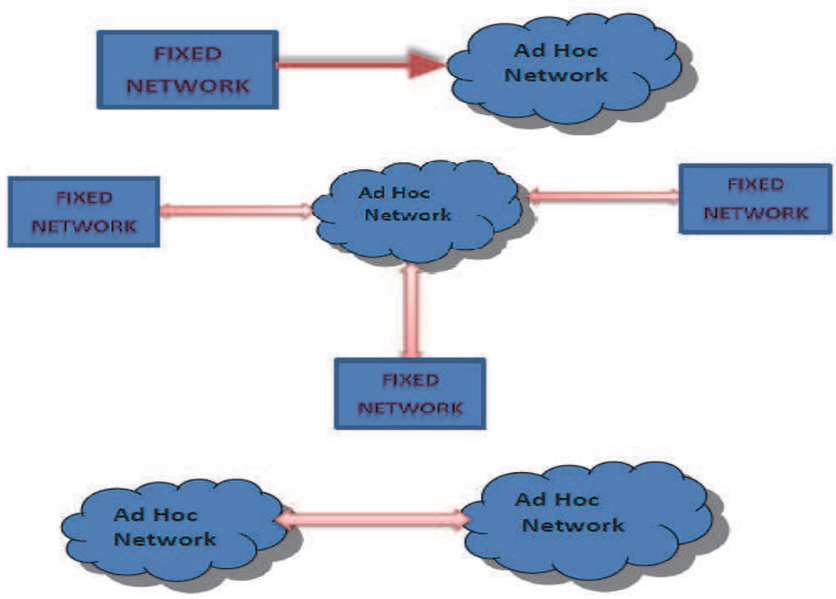

Fig. 1. Ad hoc networks employed in different configurations.

The cellular networks are organized in a master slave configuration and employ a centralized infrastructure, which in turn require base stations fixed in one location. They have a static network topology and stable connectivity. The installation requires careful planning and the setup cost is relatively high. On the other hand, ad hoc networks have less infrastructure requirements, and there is no need of a base station. These networks are highly dynamic with ever changing network topology which leads to unexpected interference and results in frequent disconnections. Ad hoc networks do not require any planning or setup of infrastructure and hence are very cost effective. Ad hoc networks when integrated with cellular networks can utilize and interface with cellular network hardware such as access points.

Ad hoc network topologies with minimal number of nodes operate more efficiently, whereas, networks with high number of nodes are relatively difficult to manage in terms of

achieving high spectral efficiency and securing the information propagating in the network. Although the issues are challenging as far as the scalability is concerned, the network still provides connectivity and enables the user to transmit urgent messages under various network and traffic conditions. Small networks are useful in applications when connecting devices in the home or office environment where a small network will be fast, efficient, and secure.

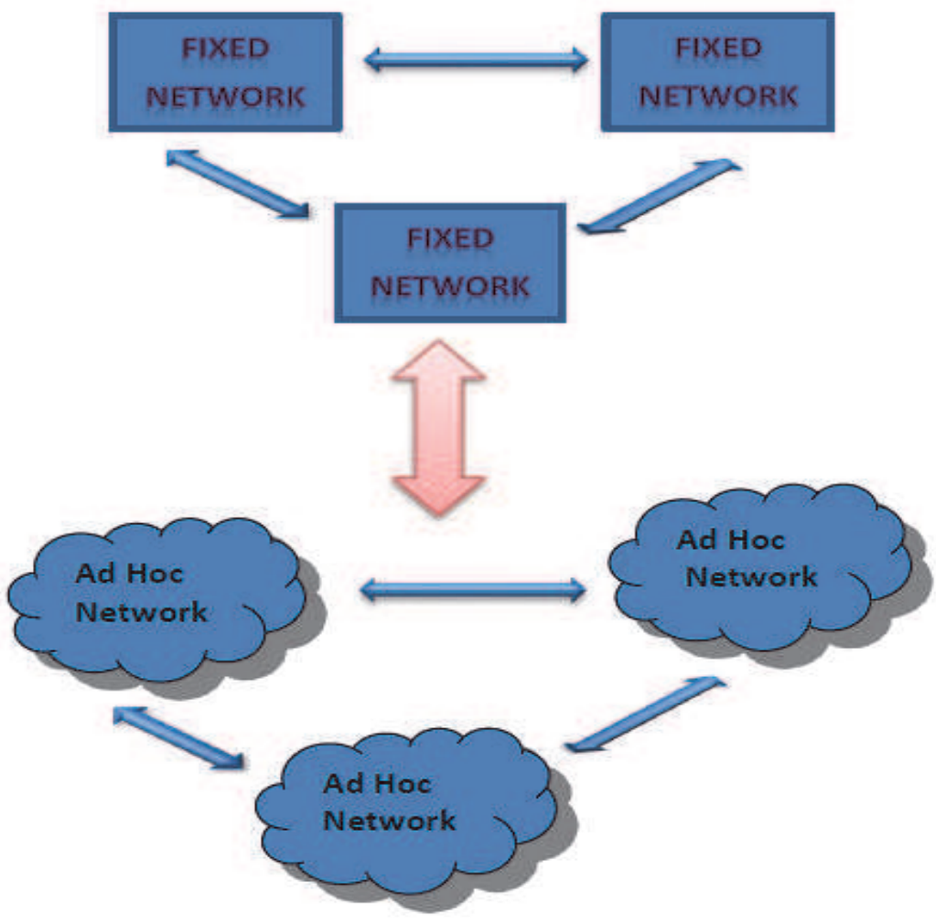

Fig. 2. Connecting fixed networks with ad hoc networks

2.1 Technologies employed in ad hoc networks

Ad hoc networks are realized using several prevailing technologies used in other wireless communication applications. The most popular physical layer standard is the IEEE 802.11. This is commonly used for WLAN services while Bluetooth is used for short range services. These technologies are successfully employed in ad hoc networks. The physical layer specifications in ad hoc networks are similar to the standards used in WLAN and Bluetooth, and 2G networks. For example, another existing and popular technology, GSM has mainly been used for voice services and offers a narrow range of services. With the development of 2.5G/3G generation of mobile communication, like GPRS, UMTS, CDMA etc., several advanced services like Internet and other multimedia applications are also provided. Several other schemes are also developed, such as IEEE 802.11/a/b/g (WLAN broadband)

and broadcast systems which include Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB) (Armeulles et al., 2004). All of these wireless communication technologies are desirable contenders for use in ad hoc networks. Although these technologies are designed for cellular and wireless local areas networks, with appropriate changes in system software can make these technologies useful for ad hoc networks applications. Bluetooth scheme is also implemented for use as short range ad hoc networks. The 4G networks include both the existing as well as future technologies and hope to provide good services with best connectivity everywhere at all times. The concept of applying 4G in military environment is called Fourth Generation on Warfare (4GM @ 4GW) which involves the use of ad hoc networks in combination with infrastructure based network. As new technologies are compatible with existing technologies, their application to ad hoc network is also anticipated (Szczodrak et al., 2007).

Recently, the main focus of research in the area of ad hoc network design is around optimizing energy consumption, the design of 3G and next generation systems also takes into consideration these requirements. The future generations of wireless equipment is also being developed on the same lines as required by ad hoc network devices. The objective of achieving higher data rate and lower transmission cost is also the main focus in the new specifications of mobile telecommunication equipments. Integration of ad hoc network with PSTN, 4G, 3G, GPRS, UMTS, 2G, and GSM is shown in Figure 3. Some of these configurations are in use while research is going on to integrate other technologies.

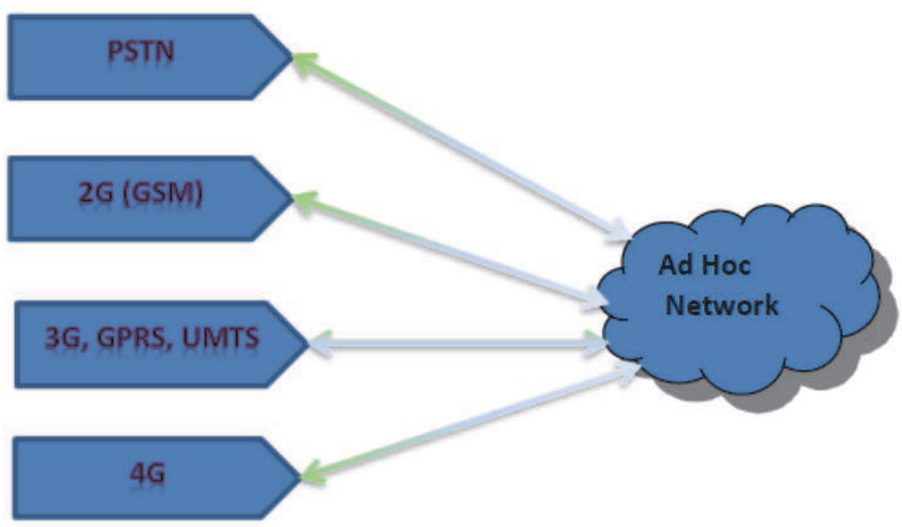

Fig. 3. Integrating ad hoc networks with the modern technologies.

Some of the features of existing and future technologies are presented below. The objective is to provide an insight into their features, capabilities, and suitability for use in ad hoc networks applications.

The 3G offers lower data rates than WLANs, where WLANs have a much smaller coverage area as compared to 3G. Wireless mesh networks (WMN) offer a solution with higher data rates and better coverage (Akildiz & Wang, 2005). The 3G system has limited support for mobility. The concept of MIMO and OFDM is used to increase the mobility, security and throughput of 4G. Space-time coding increases the reliability, high data capacity and

spectral efficiency (Fakih et al., 2009). Hence, with an increase in the network capacity, the transmission rate also increases.

Standard Wi-Fi and WiMAX have point to point architecture. Wi-Fi devices are readily available in the market. The components used in these devices are available off the shelf, which makes them an ideal candidate for use in ad hoc networks. Certain applications like VoIP and video conferencing can take down the network. WiMAX networks are high speed and designed specifically for last mile distribution but these devices are expensive.

There has been research in the field of Cellular Aided Mobile Ad hoc (CAMA) networks, operated in places where MANETs overlap cellular networks. The servers or CAMA agents are part of cellular network and have a record of registered mobile ad hoc users. CAMA operates well in metropolitan areas. Besides the peer-to-peer communication, CAMA allows the ad hoc nodes to be connected to Internet access point, which provides a cheaper Internet access without using expensive cellular channel. Only control data is handled by base station, the rest is limited to ad hoc networks. For implementing CAMA in 2G(GSM) the number of channels can be reserved (Bhargava et al., 2004).

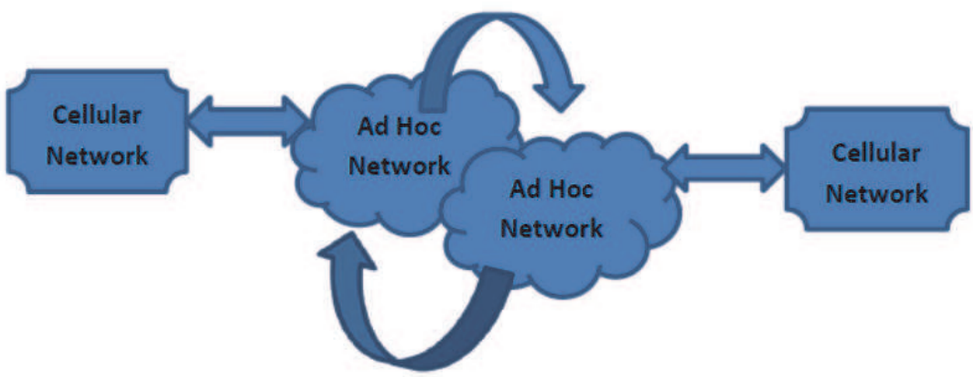

Fig. 4. Integrating ad hoc networks with cellular networks.

2.2 Applications of ad hoc networks

Ad hoc networking applications can be utilized in all kinds of networks due to their flexible nature. They are not limited to LAN or WAN but can be used in Body Area Networks (BAN), where connectivity among different types of wearable devices is required and Personal Area Networks (PAN), where connectivity between devices around a person is the objective. PDAs and notebooks can be automatically synchronized to transfer files, emails etc. A mobile phone from cellular network can connect to the PDA, allowing PDA to access cellular services without actually being part of the system. This can even lead to opening the door automatically upon your arrival at your home or office and adjust the air conditioning according to your preference. Airports can provide check in, boarding and seating services to customers as soon as they enter the airport and a lot of time can be saved by connecting to the customers' handheld device.

2.2.1 Audio applications

Certain applications like VoIP, video conferencing, file sharing etc., demand a close collaboration between network and application layers to ensure QoS. An important application is VoIP which is implemented by routing local telephone calls through the mesh.

There is no management in ad hoc networks that will ensure the QoS for services like VoIP, video conferencing and file sharing etc. Special protocols need to be designed to develop coordination between different Open System Interconnection (OSI) layers to implement VoIP services in ad hoc networks. Nodes in ad hoc networks need to recognize their Internet Protocol (IP) through Duplicate Address Detect (DAD) to ensure uniqueness. Since the IP is bound to change due to mobility, IP address cannot be used to initiate calls in ad hoc VoIP, instead a communication ID is used. To ensure security and authenticity, public and private key concept is used (Sun et al., 2005). VoIP can be used in many applications, including call center integration, directory services over telephones, IP video conferencing, fax over IP, and Radio/TV Broadcasting.

Push-to-talk (PTT) is like a walkie-talkie service defined by Open Mobile Alliance (OMA). Currently most operators are implementing PTT over cellular service. PTT performs an instant VoIP service in wireless ad hoc networks and is very useful in battle fields, earthquake and disaster relief. The growing popularity of services like Skype exploits the use of VoIP in a low cost manner. Now it is convenient for people to stay connected with other users across the world in an inexpensive way. The shortcoming is that despite the large bandwidth of IEEE 802.11, a limited number of calls can be completed successfully. In order to overcome this bottleneck, mesh networks technique can be exploited to improve routing so that the packet loss can be minimized. Here, the use of multihop ad hoc network can facilitate communication. In case of node failure, the re-routing process can result in delay or loss of packets which demand the routing process to be fast and efficient. The maintenance of end-to-end link during call is very important in all these applications (Chang et al., 2009).

2.2.2 Multimedia applications

Much work still needs to be done in the area of multimedia applications in ad hoc networks. Multimedia applications are relatively more complicated and must provide an acceptable video quality along with audio. These applications are not only used for entertainment purpose but are also useful for video conferencing. Video conferencing is beneficial for business meetings across the globes. Moreover, video conferencing can be really helpful for hearing impaired people who can communicate through sign language via video conference. Currently multimedia applications are expensive to use especially over portable devices. The use of ad hoc network in these areas can help reduce the cost and make the services more affordable for the ordinary user. Some cross layer protocols have been developed to optimize the video quality at the receiver. Since there is an increasing demand for multimedia applications, especially live streaming videos, there is a need for developing new and efficient protocols that are reliable.

2.3 Mesh networks

Wireless Mesh Networks (WMNs) are nodes organized in mesh topology consisting of mesh clients (cell phones, laptops, PDAs etc.), mesh routers and gateways, offering redundancy and reliability. Nodes themselves behave as router. WMN has a stable topology which may or may not be centralized. Non-centralized WMN can be considered a special type of ad hoc network with a more organized network topology, but unlike ad hoc networks, mesh routers are not limited in resources. The communication between other nodes is not affected by the sudden failure of a certain node. If a node fails, its neighboring nodes can find a new route among other nodes through the routing protocol. An interesting application of WMN

is 66-satellite Iridium constellation with wireless links between adjacent satellites. Two satellites can communicate by routing through the mesh without the involvement of an earth station reducing the expenses as well as the time and distance the signal will otherwise have to travel back and forth from satellite to earth station, thus avoiding additional delays. That will also allow for lesser earth stations to be mounted saving precious resources (Akyldiz & Wang, 2005).

In WMN, nodes play their role as hosts and routers. WMNs are easy to deploy in ad hoc networks because of the inherent flexibility available in the latter. WMNs provide better connectivity and reliability, enhancing network performance and are easier to troubleshoot. Local networks can be developed and latency in communication can be reduced by communicating among local nodes without involving the main server all the time. For example, several devices in a home or office, like laptops, cell phones, PDAs, printers, TV, VCR, camcorders etc., can communicate with each other without access to the hub all the time. For integration of WMN with conventional networks, backward compatibility is also required.

Ad hoc networks are very useful in situations where a predefined infrastructure is unavailable, unreliable, or is destroyed due to a disaster. Since mobile devices have limited energy resources, they prefer establishing links to their nearest neighbors, which requires less setup time and energy, instead of long haul connections. Under this scenario, ad hoc mesh networks are a natural solution. Most modern technologies, for example, Rooftop communications (now part of Nokia), Mesh networks, and Radiant networks, use a multihop mesh-based architecture instead of 3G. Mesh networks are especially beneficial for last mile solutions (Wang & Lim, 2008).

Mesh networks can provide a natural solution for use of ad hoc networks in telecommunication applications. A mesh can be regarded similar to a cell which may or may not be centralized. Communication within a mesh network will be faster, efficient and cost effective. This method to connect communication devices also solves the basic connectivity issues faced by communication networks with mixed topology. Mesh networks are especially beneficial for multimedia applications among devices located in close proximity, (e.g., in an urban environment). Due to their scalable nature, the nodes can be added to or removed from the network.

2.4 Opportunistic networking

Opportunistic networking is an interesting and novel technique for multihop ad hoc networks. In this technique, a continuous, end to end path is not required between sender and receiver. Instead, the data is not lost upon disconnection due to topology change but is buffered in the node's local memory until a suitable forwarding opportunity is found. This is very useful, especially in data transmission applications like messaging, emails, data sharing etc., where immediate end to end connection is not required. However, in applications which require a continuous link between sender and receiver, like VoIP, gaming, video streaming, conference calling, this method is not desirable (Pelusi, 2006).

Opportunistic networking is a viable solution for data applications; however, it requires storage of data, which poses a memory capacity issue. This demands efficient data storage schemes leading to the encoding of data. This technique has also been shown to achieve minimum energy data transmission in which network coding is employed to fulfill this purpose. Network coding not only provides efficient data transmission, it also improves

performance of noisy channels by adding redundancy. Network coding provides lower delays and less power consumption, hence it is suitable for ad hoc networks. In network coding, both source and relay nodes encode the data instead of repeating the source-coded data. As an alternative of receiving k packets, any set of k packets can be received and then decoded to retrieve original data. Data is organized into same length packets belonging to GF(2^s) over s bits. Assuming n packets ($M_0, M_1, \ldots, M_{(n-1)}$) of $l=L/s$ symbols, each node generates n coefficients $g_0, g_1, \ldots, g_{(n-1)}$ belonging to GF(2^s), outgoing packets x of size L are given as (Pelusi et al., 2009):

$$x = \sum_{i=0}^{n-1} g_i M_i$$

3. OSI model

Due to the independent and mobile nature of ad hoc networks, the OSI layers in ad hoc networks have a strong influence on each other. The physical layer should be able to handle the rapid changes in topology. Medium Access Control (MAC) layer should perform collision avoidance strategies. Network layer should be able to determine the optimum path for reliable communication. Transport layer handles the delay and loss of packets. Application layer should be able to handle frequent disconnections and reconnections as well as delay and packet loss. Any change in physical layer features like Signal to Interference plus Noise Ratio (SINR), modulation etc., affects the other layers of protocol stack, which need to be re-designed accordingly.

The common wireless protocol models include IEEE 802.11 PHY and MAC as well as ad hoc routing protocols like Ad hoc On-demand Distance Vector (AODV) and Distributed Source Routing (DSR). It is difficult to find an optimum solution for a network without taking into consideration all the network layers. In many circumstances, a cross layer solution is the most viable solution. At the link layer, the software design should consider scheduling, while at the network layer the design involves relaying of data or routing. Since the network resources are shared, the efficient management of resources is very important. Due to the lack of infrastructure scheduling and efficient resource, management of these networks is difficult and challenging. Interference mitigation techniques and distributed MAC protocols are used to handle the scheduling issues.

Self-Organizing Packet Radio Ad hoc Network with Overlay (SOPRANO) uses techniques to improve the capacity of cellular networks by involving ad hoc networks. It utilizes six steps of self-organization for physical, data and network layers to optimize bandwidth, routing and mobility management (Cavalcanti et al., 2005). The application layer supports network applications and manages network performance.

3.1 Physical layer

Physical layer effects include interference, noise, signal reception, fading, and path loss, which usually have an impact on routing protocols as well as on the performance of other higher layers. The physical layer handles data reception, modulation, data encryption, power management. Since there is no centralized mechanism to govern the ad hoc network, nodes are solely responsible to use their resources in the most efficient manner, therefore, power management is of pivotal importance. The protocol model is usually based on either SINR or Bit Error Rate (BER) (Rodriguez-Estrello et al., 2010).

Physical layer handles modulation/demodulation, error detection, decoding and is influenced by SINR present at the channel. Path loss models vary according to the environment in which the ad hoc networks are established (e.g., indoor environment or outdoor environment or free space, microcell or macrocell models). Physical layer preamble or signal header plays an important role in higher layer protocols as well. Common wire line medium defined by IEEE 802.3 standard requires only 8 bytes whereas Direct Sequence Spread Spectrum for IEEE 802.11 requires 192 microseconds for physical layer (Takai et al., 2001).

3.2 Data link layer

Data link layer is responsible for establishing reliable link, error control and security. It has two sub layers: Medium Access Control (MAC) and Logical Link Control (LLC). MAC is responsible for channel sharing, allotting time slots, frequency or code space among them. At the LLC, transmit power affects SINR and link capacity. The role of data link layer is important in multiplexing, frame detection, MAC and error control to ensure point-to-point and point-to-multipoint connections for reliable communication. Link layer also handles rate, power, and source/channel coding.

The main objective in MAC protocols is to optimize spectral reuse in order to maximize the channel utilization. Among many different MAC protocols, Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA), IEEE CSMA/CA 802.11, also known as Wi-Fi is the most popular.

The data link layer allows nodes to use centralized MAC such as TDMA or CDMA when connecting to cellular networks, or random access scheme like CSMA/CA in IEEE 802.11. The cellular networks can achieve a data rate of 2.4 Mb/s while ad hoc 802.11b can provide up to 11 Mb/s.

3.2.1 MAC layer

MAC layer manages the framing, physical addressing, flow control, and error correction. This layer also assists in solving conflicts between nodes and ensures efficient and reliable transmission of data. The most commonly used scheme is CSMA/CA. In CSMA-based schemes, hidden and exposed node problems can exist. MAC protocol is designed to handle this issue. Several variations of MAC protocols exist. MAC protocols can be power aware to optimize power, or can use directional antennas which avoid interference and collisions in other direction and promote spatial reuse.

The contention based MAC protocols for ad hoc networks use random access protocols and collision resolution protocols. Random access schemes such as ALOHA allow channel use for nodes as soon as it is ready. Simultaneous transmissions can cause collisions. This works for less load and provides low throughput. Slotted ALOHA is a variation providing synchronized time slots similar to TDMA and in this scheme the throughput is doubled (Kumar et al., 2006).

Dynamic reservation collision resolution protocols, such as, Multiple Access Collision Avoidance (MACA) are used to solve hidden and exposed node problems in ad hoc networks by sending RTS/CTS packets to prevent collisions. MACA does not solve the hidden terminal and collision problem completely, especially for high network traffic. Transport layer will have to promote retransmission in case of transmission failure for any reason.

Another modification of MACA involves sending RTS-CTS-DS-DATA-ACK packets which provide better throughput, though it does not solve the hidden and exposed node problem completely. Floor Acquisition Multiple Access (FAMA) scheme solves the hidden node problem by repeatedly sending the CTS packet in response to a RTS packet, until all nodes can hear the CTS even if they cannot hear RTS (Drozda, 2005).

3.3 Network layer

Network layer is responsible for routing in ad hoc networks. To integrate ad hoc networks with the current telecommunication networks, the primary requirement is to develop a routing scheme between the two systems. With the appropriate implementation of network layer, the traffic flow can be ensured between the two types of networks. This enables the entire system to handle traffic between different types of systems in an efficient manner. A handoff between the two technologies can degrade the system performance which demands for application layer to handle the network requirements and ensure QoS requirements. The appropriate architecture of network layer is an important design consideration, which is not only necessary for providing connectivity, but it is also important for avoiding unnecessary bottlenecks or congestion points in order to restrict transmissions (Akyol et al., 2008).

3.3.1 Routing protocols

Routing in ad hoc network configurations is a challenging and important task in networks which lack central management. The ad hoc networks rely on efficient routing protocols which provide connectivity among various sources and destinations. Several routing protocols have been developed to serve different purposes and depend on network resources, changing network conditions and other parameters.

The routing protocols are broadly divided into table driven (or proactive) and on demand (or reactive) protocols. In addition, flow oriented protocols also exists which take into consideration the flow of data packets in the network. A combination of proactive and reactive protocols is classified as hybrid routing protocols. These protocols have functionality of both types of protocols incorporated in a single system. There are other types of protocols, which are basically variants of reactive or proactive protocols, which include hierarchical routing protocol, backpressure routing protocol, host specific routing protocols, power aware routing protocols, multicast routing protocol, geographical multicast routing (Geocasting) protocol, and optimized link state routing protocol.

The table driven (proactive) protocols maintain up-to-date information of route between all nodes. Routing information propagates through the network to keep the table recent. However, these protocols are not suitable for a highly dynamic network where node mobility is high. Table-driven protocols include Destination-Sequenced-Distance-Vector (DSDV) and Wireless Routing Protocol (WRP). DSDV is a routing protocol where every node maintains a routing table with a destination sequence number (Abolhassan et al., 2004). Cluster head Gateway Switch Routing (CGSR) is a special case of DSDV and uses clustered multihop mobile network for cluster-head-to-gateway routing. In WRP, each node maintains four tables: distance table, routing table, link cost and Message Retransmission List (MRL) tables. These tables are updated by sharing of information among neighboring nodes (Royer & Toh, 1999).

Source-initiated or on-demand routing protocols include AODV, DSR, Temporally Ordered Routing Algorithm (TORA) and Signal Stability Routing (SSR) protocols. Dedicated Source

Routing (DSR) involves route discovery and route maintenance. In route discovery, node broadcasts route request to its neighbors. The neighboring nodes in range add their ID to route request and initiate a rebroadcast which eventually reaches the destination or to the node that has a recent route to it. Nodes maintain a route cache, if a route is found in route cache, the node will return a route reply to source and forward the packet through cached route to the destination node.

AODV discovers routes on demand instead of keep updating the routing information, thereby reducing the number of broadcast messages. When a source node desires to send a packet, it checks its routing table for a route to the destination and then transmits. If route is not found, it broadcasts a route request to its neighbors which rebroadcasts it until a route is eventually discovered. Route maintenance is also important. If a node moves away, it sends a link failure notification to its neighbors to ensure deletion of that route and the source can reinitiate the route discovery process (Abolhasan et al., 2004).

TORA finds multiple routes in a highly dynamic network by making the nodes keep the routing information for one hop neighbor. It has three basic functions: route creation, route maintenance and route erasure and uses a height metric to create a Directed Acyclic Graph (DAG) (Royer & Toh, 1999).

3.4 Transport layer

The existing telecommunication applications use Transport Layer Protocol (TCP). In TCP, network congestion is detected by the packet loss. This scheme works well for wired and fixed topology networks, but is not suitable for ad hoc networks due to the continuous change in network topology, higher error rate and frequent disconnections. Moreover, in ad hoc networks, transport layer cannot be treated isolated for better network performance, since physical and MAC layers and routing protocols also have a significant effect on the transport layer. Packet loss may not be due to congestion in transport layer but due to disconnection, node movement, lower SINR or route change. TCP misinterprets route failures and wireless errors as congestion while delay causes it to initiate unnecessary retransmissions. Packet loss due to mobility is also detected as congestion.

Performance degradation of TCP, the transport layer protocol, is responsible for packet loss and congestion, delay and overlooked handoffs in cellular networks and is sometimes used with some modifications for ad hoc networks as well. Two kinds of handoffs exist; horizontal handoffs take place between the access points of the same network, while vertical handoffs are between different networks. Cellular networks handle horizontal handoffs at link layer and network layer handles mobility management. Vertical handoffs have to take into account when to start and how to regulate traffic for the handoff. When TCP is implemented in ad hoc networks, channel errors can be mistakenly termed as congestion and result in retransmissions causing degraded system performance especially in multihop networks. In single hop ad hoc networks, collisions are reduced but channel utilization is inefficient.

TCP performance also depends on the routing protocol used. Liu (Liu et al., 2011) demonstrated the effect of different routing protocols like AODV and OLSR. According to their study, OLSR provides better TCP performance for relatively slower node mobility as compared to AODV.

Ad hoc Transport Protocol (ATP) is specially designed for MANETs. It uses lower layer information, e.g., initial rate feedback, regular rate-based feedback from neighbors to control sending rate and path failure notification in case of route failure. Unlike conventional TCP

which uses window-based transmission, ATP uses a rate-based transmission. ATP segregates congestion and reliability and an ACK signal is not required to clock the packet transmissions. ATP uses Selective Acknowledgment (SACK) reported periodically to detect packet loss and ensure reliability besides reducing traffic load on reverse path. ATP avoids bottleneck by accurate knowledge of maximum transmission rate obtained by feedback from neighboring nodes. ATP is incompatible with the TCP protocols and requires major modifications and redevelopment in the applications that use the older TCP version.

3.5 Power management

Since nodes in ad hoc networks are mobile, they depend on battery power and thus have limited energy. While the idea of running several multimedia applications is quite alluring, it also requires huge battery power, therefore, power management is an important issue in ad hoc networks.

Power management issue involves all the layers of protocol stack from physical to network layer. The energy efficient routing protocols are designed to reduce power consumption and take into account the remaining power of nodes in making routing decisions. To conserve power, links that are not used are shut off; network is properly scheduled to avoid wastage of energy due to congestion and collisions and by avoiding redundant transmissions (Goldsmith, 2002).

Most transmissions are performed in ad hoc networks through broadcasting. There are several broadcasting techniques that can be used, for example, blind flooding (each node rebroadcasts), probabilistic broadcasting and broadcasting based on area or neighbor knowledge. While blind flooding is the simplest approach, it has lot of redundancy and wastes too much power. Cluster based and tree based (source dependent or source independent) broadcast methods are also used where nodes transmit broadcasts messages to other members of clusters or trees. These methods belong to proactive routing.

Power management is a cross layer issue in ad hoc networks. At data link layer, power can be optimized by putting the unused nodes in standby mode, choosing consecutive slots for transmission and reception, avoiding collisions and retransmissions. At network layer, power consumption is minimized by using multihop routing, optimizing and lowering the number of control messages and using efficient routing techniques. The transport layer helps minimize power by controlling packet loss and retransmissions. Application layer adopts a dynamic QoS framework, helps power control by caching frequently used data/information and suppressing unimportant data to allow transmission of important information (Kawadia & Kumar, 2005).

4. Cognitive radio

Cognitive radio is a dynamic spectrum access technique and provides high bandwidth by opportunistically sharing the wireless channel with licensed users. The use of cognitive radio approach in ad hoc networks and the utilization of Dynamic Spectrum Access (DSA) technique is a promising method in further increasing the efficiency of radio frequency usage (Akyildiz et al., 2009). Cognitive Radio (CR) must be able to determine when and which portion of spectrum is available and select the best available channel, coordinate access to this channel with other ad hoc network users and vacate the channel when licensed user is detected. The cognitive radio detects an unused spectrum and allocates a channel to users. If more than one users need to share the spectrum, it coordinates the spectrum access

to avoid collisions. If a primary user needs to access the spectrum, CR users have to vacate that spectrum and communication is continued in some other vacant portion of spectrum. CR network is not aware of the exact location of other nodes or the amount of interference offered by other nodes. There is a maximum interference limit (usually termed interference temperature) on each receiver which they can tolerate. If the CR users do not exceed this limit, they can use the channel. When a Primary User (PU) wants the channel, the CR users change their frequency of operation through a spectrum handoff. Each time a handoff occurs, the network needs to modify its protocols to avoid performance degradation during handoff. Handoff may be due to PU, node mobility or degradation in QoS. A temporary communication break-off cannot be avoided during a handoff since the CR user has to search for the next available band. The spectrum discovery process can take time and create longer switching time. The transmitter has to determine a new route according to the new spectral band to allow the commencement of interrupted communication.

Independent spectrum management involves opportunistic spectrum use (use of primary user's spectrum to avoid additional interference) or dynamic spectrum access. Regulated spectrum management involves pooling (two or more parties decide to pool resources), leasing, sharing or negotiating. *Spectrum sensing, spectrum decision* and *spectrum sharing* are the three important steps in designing a cognitive radio (Akyildiz et al., 2009).

Spectrum sensing is responsible for determining the available spectrum to be used by CR users. At the same time it should be capable of providing alternate vacant spectrum in case a primary user appears in the scenario. The CR users have to search for the available spectrum individually. Since the observation range of each user is limited, they have limited opportunity to access the spectrum. Cooperation among CR users can help to increase the efficiency of spectrum sensing and provides more accurate results.

Spectrum decision is also a crucial step in CR, since it enables the CR users to choose the best available spectrum band. It depends on the behavior of primary users as well as channel characteristics. It involves *spectrum characterization* (characteristics of spectrum as well as PU activity model), *spectrum selection* (choosing the best spectrum to ensure QoS) and *reconfiguration* (modifying protocols and hardware according to CR users' requirements). Unlike traditional ad hoc networks, CR users maintain a heterogeneous spectrum over time and space. Hence the resource allocation is dynamic and QoS parameters change with the change in spectral band. Moreover, the spectrum selection and decision is highly correlated with the routing protocols. Since the topology of CR can change due to their ad hoc nature, spectrum switching demands a whole new routing protocol and existing protocols for ad hoc networks may not be efficient or even working.

Spectrum sharing is another important development in CR networks, where CR users share the opportunistically obtained spectrum with each other. The users have to cooperate and avoid causing interference to other CR users. Spectrum sharing is performed within a band during a communication session. This involves proper resource allocation and designing a suitable MAC protocol to allow the coexistence of CR users among themselves (intra-network) and/or with other CR networks (inter networks). MAC protocols in case of CR have to take into account the spectrum sensing and sharing. Random access, time slotted and hybrid approaches are used to design MAC protocols in case of CR. Random access scheme is based on CSMA/CA. Dynamic Open Spectrum Sharing (DOSS) MAC protocol solves the hidden and exposed node problem. It is complex and uses spectrum inefficiently.

Time slotted MAC protocol such as Cognitive MAC (C-MAC), define slotted beaconing periods. Protocol determines the best available channel based on the beacon. C-MAC

defines super frames for *data transfer period* (DTP), *beacon period* (BP) and *quiet period* (QP) (Akyildiz et al., 2009).

Primary user detection is very important in cognitive radio, as every cognitive user must vacate the spectrum upon detection of primary user. Primary user detection involves detection of transmitter, receiver (PU transmitting or receiving data in the communication range of CR users) and interference temperature management. Methods like matched filter, energy detection and feature detection are used to detect transmitter. Matched filter technique requires the CR users to have complete knowledge of primary user characteristics. Energy detection requires noise power. Energy detector can determine the presence of signal but signal type cannot be differentiated. Primary and CR users both cannot be distinguished, resulting in false alarm. Feature detection is based on determining the features of primary users like symbol rate, spreading codes, modulation type and cyclic prefix etc. This scheme is robust and has optimal performance, therefore, makes it most suitable for the case of ad hoc networks.

Hybrid protocols use partial slotting with synchronized control signaling. The access to channel may be completely random with the control or data durations. Resource allocation is another important factor for CR users, which can benefit by intelligently managing and utilizing their limited resources. Game theoretical concepts have been invoked to ensure the best possible strategies for CR users as well as to develop cooperation among them.

The Common Control Channel (CCC) coordinates transmission and provides spectrum information exchange between users. Since the parameters like channel quality, network load, access time are not initially known to CR users, CCC has to be designed with almost no information. Moreover, a primary user can make the spectrum unavailable for CR user at any point, hence an always on CCC is required to reliably send the control information to new spectrum. CCC can be in-band or out-of-band. In-band CCC is temporary and for a specific purpose only and uses the same data channel, avoiding additional spectrum switching cost. Out-of-band CCC has separate data and control signaling and CCC spectrum reservation may be permanent or for short duration.

CR users can simultaneously transmit to different users by tuning each transceiver to different spectral bands. This allows less power to be used in each band minimizing the interference. Knowledge of primary user activity is again very important as it helps to minimize the conflict and allows CR users to devise a strategy according to the PU activity.

Transport layer protocols must be designed to make them aware of PU activity as well as channel. Akyildiz (Akyildiz et al., 2009) developed a transport layer protocol for CR ad hoc networks named TP-CRAHN, which involves six states:

- Connection establishment (involves a three-way handshake for connection setup)
- Normal state (information is piggybacked over incoming ACK to aware the source)
- Spectrum sensing (minimize spectrum sensing time by keeping track of PU history)
- Spectrum change (source TCP state is frozen and after spectrum selection bandwidth is estimated and communicated to source)
- Mobility prediction (next hop is predicted using Kalman filtering)
- Route failure

5. Security

Security is an important concern in communication. In ad hoc networks, the problem is further complicated due to the absence of infrastructure and dynamic topology. The lack of

centralized control makes the system more vulnerable to attacks and threats. Nodes can enter or leave the system at any time, making it difficult to identify a malicious node which might be re-joining the system and launching attacks from different locations repeatedly. The wireless channel, mobility of nodes, dynamic network topology and dependence on routing protocols all make the ad hoc networks more prone to attacks.

Security concerns include attacks from malicious users, availability, authentication, confidentiality, integrity, non-repudiation, routing protocol protection. Attacks may be *external* (outside network or denial of service from nodes) or *internal* (nodes inside network are turned malicious), *Passive* (eavesdropping) or *Active* (replication, modification and deletion of data). Passive attacks are more concerned with confidentiality and are relatively easier to combat. Active attacks are much more threatening to all security areas from authenticity to non-repudiation and require sophisticated protection schemes on all fronts (Yang et al., 2004). Attacks can be made directly on the routing to disrupt the source-destination path or attacks can be made on forwarding to cause packet loss.

Hackers can affect the security and reliability of network by deleting packets, manipulating the routing table, sending erroneous messages to nodes, jeopardizing the availability, integrity and authenticity of network. Attackers can also turn nodes inside the network into malicious nodes which can launch attacks from within. These nodes may appear to work correctly, but they may modify or misuse the routing protocols to undetectably disrupt routing, causing disconnections. These nodes can also inject more malicious nodes in the routing strategy and use the whole network for their malicious objectives. They can launch denial of service attacks by additional transmissions or unnecessary computations to exhaust battery power of nodes (Zhou & Haas, 1999).

Authentication is difficult to maintain due to the lack of centralized authority issuing certificate. Integrity of data involves key which may be symmetric or asymmetric (all nodes need to have others' public keys). Confidentiality can be ensured by changing the key every time a node enters or leaves the system. Availability involves service continuity despite Denial of Service (DoS) attacks. These attacks can be launched from any layer, physical, MAC or Network layer. Confidentiality means ensuring the protection of data from unintended users. This is especially important in military applications where information leakage to enemy can be detrimental. Integrity involves making sure that transmitted data is never corrupted, either due to channel conditions or malicious node involvement. Authentication protects the identity of a node and helps avoid attackers. Non-repudiation ensures that source node (or relay) cannot deny the initiation of message.

Security issue can be solved by protecting the MAC layer; encrypting everything, verification of authenticity and making sure the private keys are secure. Keeping too many keys and different security levels at every layer assists in solving security issues. Public Key Infrastructure (PKI) can be used but asymmetric cryptography is expensive. In PKI, every node has a public/private key pair. The public part is made known to all other nodes, keeping the private key confidential. A Certificate Authority (CA) manages the key by distributing its own public key and signing certificate binding keys to nodes. Usually, more than one CA is used to ensure protection in case of unavailability of CA or in cases when CA itself might be compromised. Malfunctioning of CA can threaten the security of the whole network. CA technique can only be implemented in ad hoc networks if these are integrated with cellular systems where they can benefit from the centralized management of cellular networks. When working in isolation, MANETs cannot use central key management systems, rather a distributed key management scheme is used that relies on secret sharing where key is distributed using cryptography. Another

method is that each node builds its trust chart based on the nodes it trusts and matches it with the node it wants to communicate with.

Security can be maintained by verifying the authenticity of message between communicating nodes. Another approach to improve security is through Intrusion Detection (ID). To ensure route security, routing protocols use multi-hopping and authenticity is verified on hop-to-hop basis. All intermediate nodes validate digital signatures cryptographically.

Byzantine robustness, which is a strict self-stabilization policy, ensures the proper functioning of routing protocol even in the presence of some malicious nodes. Routing protocols should be designed so that they not only recover from attacks but also ensure the normal functioning of system even during attacks. Trust maintenance is also very important in ad hoc networks.

Secure routing protocols used in MANETs include Secure Efficient Ad hoc Distance vector (SEAD) where source selects a random seed and sets the maximum hop count. Using a hash function, source computes hash value h(seed). Fuzzy logic is employed in protocols to improve security. In FL-SAODV protocol, each mobile host uses a secure key with its neighbor nodes and relies on the secret key and node's environment. FL-SAODV uses security level as one of the parameters while choosing a route. Moreover, it aims to minimize the transmitting time by choosing shortest path so that attack time is reduced. Dynamic Destination Multicast (DDM) protocol is another security protocol where only sender has the authority to control information transmission. This protocol is based on grouping and does not allow arbitrary nodes from outside to enter the group without prior authorization.

Another protocol to improve security is *i-key* protocol where secret key is generated using previous data as seed which ensures that the decryption can only be performed by sender or authorized client. Alliance of Remote Instructional Authoring and Distributed Networks for Europe (ARIADNE) is another secure routing protocol that uses shared secrets or digital signatures and utilizes DSR and symmetric cryptography. This works for one attacker only. SEcure Neighbour Discovery (SEND) Vector has lower processing time and uses one way public key signed hash function. Authenticated Routing for Ad hoc Network (ARAN) protects against malicious nodes using pre-determined public key.

SRP is another scheme that provides better security by splitting a message into fragments and transmitting them along different paths. The original message can be reconstructed if a certain number of fragments are correctly received.

Security also depends on number of neighbors and key length. Frequently changing the key also helps in improving security by making it less vulnerable. It has been found that security level is directly proportional to the key changing frequency and key length and inversely proportional to the number of neighboring nodes. Security level is also dependent on the application. Some applications are more sensitive and require higher level of security, for example mobile banking and E-commerce applications. Other applications like VoIP and video conferencing require privacy as well as maintain QoS.

5.1 Intrusion detection

Intrusion detection involves in determining whether the system is under attack or not. Two types of Intrusion Detection Schemes (IDS) are used: host-based or network based. Network based IDS works at gateways and examines network packets. Host based IDS uses operating system data to analyze program or user activities. IDS are categorized into *misuse detection*

and *anomaly detection*. Misuse detection identifies intrusion using patterns of known attacks or weak spots. Anomaly detection detects deviations from normal activities.

6. Social impacts

The integration of ad hoc networks in the current telecommunication system will greatly affect the lifestyle of an ordinary person. While the people already involved in technology will feel facilitated by this new system, an ordinary person will also find these services useful as well as entertaining.

At home ad hoc networks can provide connectivity to different personal devices such as notebooks, PDAs, camcorders, TV, cell phones and even appliances which include air conditioners, microwave oven, intercom etc. It also helps people in getting organized. Since no cost is required to establish the infrastructure, the services offered are quite cheap and are attractive for masses.

Staying connected is also very important for business professionals as it helps broaden their horizon by exploring new markets. Important business transactions can be completed and meetings with worldwide companies can be held through video conferencing. Improved telecommunication has been linked to economic growth.

With the growing popularity of social networking sites like Facebook and Twitter, especially among the younger generation, the demand to have an all time Internet access everywhere is increasing. Ad hoc networks can provide connectivity even in remote areas at a very affordable price.

Due to the access to multimedia applications and availability of live streaming, people can watch TV on their potable hand held devices. This is especially very attractive for people who are interested in sports and don't want to miss their favorite games. Now people don't have to walk in a music store or theater to get a CD of their favorite songs or watch their favorite movie.

6.1 Impact on business players

Several stake holders are involved from device manufacturers, infrastructure equipment vendor, operating system providers, application developers, service providers, and customers. It is difficult to replace the existing infrastructure so the current network operators will still be in business. Skills of technical people will still be required for the new system development. Operators can support ad hoc networking in public venues like airports, hospitals, hotels, stadium, and theatres.

Device manufacturers face more responsibility and challenge, because ad hoc devices differ from current devices. Ad hoc network devices are capable of routing. Some of the functions available in mobile devices can be replaced or moved to the device itself. For example, vehicular applications can be mounted on the vehicle itself instead of integrating with the hand held device.

With the increase in devices and also the available applications, the operating system needs to be modified and improved. This opens up more business opportunities for providers of operating systems. The operating systems have to deal with routing and security issues of ad hoc networks and handle the bottle necks in the network.

Application developers can take advantage of technological developments, posing no threat to existing markets and creating new frontiers. Applications can be provided to customers without the involvement of mobile operators. Application service providers have more benefit in large centralized networks than smaller ad hoc networks. But they can offer

variety to customers and can gain from services which require the users to be in close proximity of each other.

Network operators can be affected in a variety of ways. Although the demands for multiple services are on the increase, most facilities can be provided free of cost in ad hoc networks. The monopoly of network operators will be affected and new players will come forward in a bargaining position. Network operators will cease to be in absolute authority or they may chose to provide ad hoc networking services themselves.

Mobile portal providers also have market in large networks but new demands may emerge for applications. Supporting services providers will have to broaden their services to include security and cater to the needs of operators, portal providers and application service providers. Operators of venues can provide services to their customers without the involvement of traditional network operators. For example, airport or train stations can track lost or stolen baggage using ad hoc networks (Stanoevska-Slabeva & Heitmann, 2003).

7. Conclusion

In this chapter we give the readers in depth information about the role of ad hoc network in mobile telecommunications. Various aspects of these networks are discussed, ranging from the integration issues, adaptation to radical changes, and layered implementation of ad hoc networks. Special emphasis has been placed on the routing protocols as they play a very crucial role in the otherwise autonomous ad hoc networks. The use of mesh networking has been discussed to improve the connectivity and resource management in small area networks. We argue that the ad hoc networks have a definite advantage in specific situations over other existing network technologies and systems, and therefore, can be used in wide range of applications. It has been discussed that ad hoc networks can also improve the performance of existing networks and provide a wider range of services if integrated in the existing networks. The use of other existing and upcoming technologies in ad hoc networks is also discussed. The implementation of cognitive radio technology has been specifically presented to show how the available spectrum can be used efficiently. The security aspect of ad hoc networks is shown and methods are proposed to improve the security of the vulnerable ad hoc networks. We also present the future trends and social issues of the use of ad hoc networks from the perspective of users as well as from business point of view.

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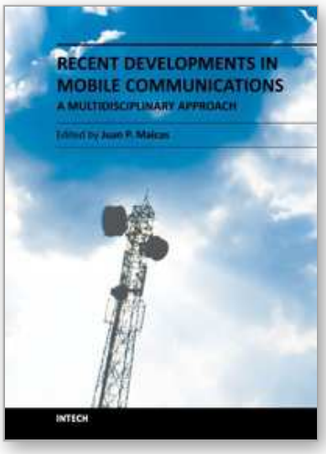

Recent Developments in Mobile Communications - A Multidisciplinary Approach

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Recent Developments in Mobile Communications - A Multidisciplinary Approach offers a multidisciplinary perspective on the mobile telecommunications industry. The aim of the chapters is to offer both comprehensive and up-to-date surveys of recent developments and the state-of-the-art of various economical and technical aspects of mobile telecommunications markets. The economy-oriented section offers a variety of chapters dealing with different topics within the field. An overview is given on the effects of privatization on mobile service providers' performance; application of the LAM model to market segmentation; the details of WAC; the current state of the telecommunication market; a potential framework for the analysis of the composition of both ecosystems and value networks using tussles and control points; the return of quality investments applied to the mobile telecommunications industry; the current state in the networks effects literature. The other section of the book approaches the field from the technical side. Some of the topics dealt with are antenna parameters for mobile communication systems; emerging wireless technologies that can be employed in RVC communication; ad hoc networks in mobile communications; DoA-based Switching (DoAS); Coordinated MultiPoint transmission and reception (CoMP); conventional and unconventional CACs; and water quality dynamic monitoring systems based on web-server-embedded technology.

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