CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The extensive literature collected related to the performance improvement of IEEE 802.15.4/ZigBee WSN using the Beacon enabled and non-beacon enabled mode and ZigBee fundamentals are reviewed and presented in this chapter. OPNET modeler is used for analysis instead of the other network simulators like OMNET++, NS-2 which are also presented in this chapter. Further, the summary of review of literature is furnished at the end of the review.

2.2 WIRELESS TECHNOLOGIES

Wireless communication is the transfer of information between two or more points that are not connected by an electrical conductor. Applications may involve point-to-point communication, point-to-multipoint communication, broadcasting, cellular networks and other wireless networks. Wireless network refers to any type of computer network that utilizes some form of wireless network connection. Wireless networks have different types namely Wireless LAN, Wireless WAN and Wireless MAN.

Within the broad organization of the Institute of Electrical and Electronics Engineers (IEEE), the 802 group is the section that deals with network operations and technologies (Figure 2.1). Group 15 works more
specifically with wireless networking, and Task Group 4 drafted the 802.15.4 standard for a Low Data Rate Wireless Personal Area Network (WPAN).

![IEEE 802 LAN/MAN Standards Committee](image)

**Figure 2.1 IEEE Committee**

The development of WSNs was initiated by the United States during the Cold War. A system of acoustic sensors (hydrophones) was deployed at strategic locations on the ocean bottom, in order to detect and track quiet Soviet submarines. This system of acoustic sensors was called Sound Surveillance System (SOSUS).

In addition, during the Cold War, networks of air defense radars were developed and deployed to defend the continental United States and Canada. These sensor networks generally adopt a hierarchical processing structure where processing occurs at consecutive levels until the information about events of interest reaches the user. In many cases, human operators play a key role in the system.
Modern research on sensor networks started around 1980 with the Distributed Sensor Networks (DSN) program at the Defense Advanced Research Project Agency (DARPA). One of the newest WSN projects is the Wireless Self-Sustaining Sensor Network (WSSN), project of Institute of Computer Technology at the Vienna University of Technology (Vienna University of Technology-TUV).

Jin-Shyan Lee et al (2007) have presented a comparison for four different protocol standards (Bluetooth, ultra-wideband, ZigBee and Wi-Fi (over IEEE 802.11)) for short range wireless communications with low power consumption. From an application point of view, Bluetooth is intended for a cordless mouse, keyboard, and hands-free headset, UWB is oriented to high-bandwidth multimedia links, ZigBee is designed for reliable wirelessly networked monitoring and control networks, while Wi-Fi is directed at computer-to-computer connections as an extension or substitution of cabled networks. He also proposed a study of these popular wireless communication standards, evaluating their main features and behaviors in terms of various metrics, including the transmission time, data coding efficiency, complexity, and power consumption. He believed that the comparison presented in this paper would benefit application engineers in selecting an appropriate protocol.

Koubaa et al (2005) have provided the overview of the technical features of the physical layer and the medium access control sub layer mechanisms of the IEEE 802.15.4 protocol that are most relevant for wireless sensor network applications. He also discussed the ability of IEEE 802.15.4 to fulfil the requirements of wireless sensor network applications.

Jin-Shyan Lee et al (2005) have established a realistic environment for the preliminary performance evaluation of the IEEE 802.15.4 wireless networks. Several sets of practical experiments are conducted to study its
various features, including the effects of 1) the direct and indirect data transmissions, 2) CSMA-CA mechanism, 3) data payload size, and 4) beacon-enabled mode. The data throughput, delivery ratio and Received Signal Strength Indication (RSSI) are investigated as the performance metrics. He concluded that by featuring its simplicity, low power consumption, low cost connectivity and device-level networking would make IEEE 802.15.4 suitable for wireless sensor network applications in the practical industry.

Howitt et al (2003) have proposed that IEEE 802.15.4 is a standard addressing the needs of Low-Rate Wireless Personal Area Networks or LR-WPAN with a focus on enabling wireless sensor networks. The standard is characterized by maintaining a high level of simplicity, allowing for low cost and low power implementations. Its operational frequency band includes the 2.4 GHz industrial, scientific and medical band providing nearly worldwide availability; additionally, this band is also used by other IEEE 802 wireless standards. Coexistence among diverse collocated devices in the 2.4 GHz band is an important issue in order to ensure that each wireless service maintains its desired performance requirements. He also presents a brief technical introduction of the IEEE 802.15.4 standard and analyzes the coexistence impact of an IEEE 802.15.4 network on the IEEE 802.11b devices.

Ferrari et al (2006) have evaluated the performance of realistic wireless sensor networks in indoor scenarios. Most of the considered networks are formed by nodes using the ZigBee communication protocol. For comparison, he also analyzed networks based on the proprietary standard Z-WaveTM. Two main groups of network scenarios are proposed: (i) scenarios with direct transmissions between the remote nodes and the network coordinator, and (ii) scenarios with routers, which relay the packets between the remote nodes and the coordinator. The sensor networks of interest are evaluated considering different performance metrics. In particular,
we show how the Received Signal Strength Indication (RSSI) behaves in the considered scenarios. Then, the network behavior is characterized in terms of End-to-End delay and Throughput. In order to confirm the experiments, analytical and simulation results are also derived.

Khaled Shuaib et al (2007) have presented the performance evaluation of IEEE 802.15.4. WLAN standard (Wi-Fi) and the WPAN standard (Bluetooth and ZigBee) products utilize the same unlicensed 2.4 GHz ISM band. Co-existence between such wireless technologies within the same frequency spectrum is crucial to ensure that each wireless technology maintains and provides its desired performance requirements. He has provided a brief description of the newly introduced ZigBee standards including the Physical (PHY) and Media Access Control (MAC) layer. It focused on developing MatLab/Simulink models for the ZigBee protocol and the performance evaluation of these models. Several simulations were run and the results were analyzed for the different scenarios. The results showed how the relationship between the signal Bit Error Rate (BER) and Signal to Noise Ratio (SNR) was affected when varying the data rate and power. Furthermore, this paper investigated the co-existence of WLAN (IEEE 802.11g) with ZigBee (IEEE 802.15.4) by quantifying potential interferences and examining the impact on the throughput performance of IEEE 802.11g and ZigBee devices when co-existing within a particular environment. The effect of ZigBee on IEEE 802.11g was compared with the effect of Bluetooth under the same operating conditions.

Bahareh Gholamzadeh et al (2008) have discussed about different sources of power consumption in wireless sensor networks and several design concepts is presented which result in to decreasing the consumed power and so enhancing the life time of the network.
Soo Young Shin et al (2007) have analyzed the Packet Error Rate (PER) of IEEE 802.15.4 low rate WPAN under the interference of IEEE 802.11b WLAN. The PER is obtained from the BER and the collision time. The BER of IEEE 802.15.4 is obtained from the Offset Quadrature Phase Shift Keying (OQPSK) modulation. The collision time is calculated under assumption that the packet transmissions of the IEEE 802.15.4 and the IEEE 802.11b are independent. Because the bandwidth of IEEE 802.11b is larger than that of IEEE 802.15.4, the in band interference power of IEEE 802.11b is considered as the Additive White Gaussian Noise (AWGN) for the IEEE 802.15.4. For an accurate calculation, the in-band interference power ratio of the IEEE 802.11b is considered with different frequency offsets between IEEE 802.15.4 and IEEE802.11b. To obtain the ratio, the power spectral density of the IEEE 802.11b is considered. The simulation results are shown to prove the analysis. If the distance between the IEEE 802.15.4 and IEEE802.11b is longer than 8 m, the interference of the IEEE 802.11b does not affect the performance of the IEEE 802.15.4. If the frequency offset is larger than 7 MHz, the interference effect of the IEEE 802.11b is negligible to the performance of the IEEE 802.15.4. Therefore, three additional channels of the IEEE 802.15.4 such as 2420 MHz, 2445 MHz, and 2470 MHz can be used for the coexistence channels under the interference of the IEEE 802.11b. Finally he suggested the coexistence criteria for the IEEE 802.15.4 and IEEE 802.11b will be useful for designing and implementing networks using both IEEE 802.15.4 and IEEE 802.11b.

Wireless sensor networks continue to emerge as a technology that will transform the way we measure, understand and manage the natural environment. For the first time, data of different types and places can be merged together and accessed from anywhere. Some significant progress has been made over the last few years in order to bridge the gap between theoretical developments and real deployments, although available design
methodologies and solutions are still relatively immature. As a consequence, widespread use of WSNs for environmental proposes is not yet a reality. It is predictable that in the near future any object will have an Internet connection – this is the Internet of Things vision. In smart cities, the environmental data will provide usefully information to the citizens. For example, air quality, transportation information, emergency services and so on. The citizens can access to this information via Internet.

Nowadays, the IP suite protocol support in environmental monitoring is inconsistent. It is necessary to design new protocols and evaluate the existing ones. Assess the major benefits associated with the support of the IP protocol on all nodes, using simulation and testbeds is fundamental.

Riaz Ahamed et al (2005) have presented the Role of ZigBee Technology in Future Data Communication System. He also discussed about ZigBee Characteristics, Frame Structure and Security of ZigBee Technology.

Waqas Ikram et al (2010) have presented Wireless Communication in Process Automation. The advancements in wireless networking technology, specifically in the short-range wireless networking technology, offer an enormous opportunity for wireless connectivity of field devices both in oil and gas and other chemical processing plants. The prerequisite of a field network includes real-time support for mixed traffic, availability, security, reliability and scalability in a harsh industrial environment. These conditions have to be fulfilled by any wireless network in order to operate. He also presented a brief overview of the requirements for wireless in process automation, relative standings of existing short-range wireless network technologies based on the outlined criteria, and associated shortcomings. Furthermore, an examination of emerging industrial wireless standards which
are designed to address the unique and stringent requirements of the process industry is presented.

2.3 NON BEACON ENABLED MODE OF IEEE 802.15.4

The IEEE 802.15.4 MAC Layer supports two modes namely Beacon Enabled Mode and Non Beacon Enabled Mode. In Non-Beacon Enabled, all the nodes will check the Channel availability to transmit the packet. If the Channel is idle, then node will transmit the packets. Otherwise it will check continuously until channel is idle.

Sukhvinder et al (2010) have investigated the performance of WPAN based on various topological scenarios like: cluster, star and ring. The comparative results have been reported for the performance metrics like: Throughput, Traffic sent, Traffic received and Packets dropped. The results indicate that throughput is maximum (79.887 Kbits/sec) in case of cluster topology while it is 31.815 Kbits/sec in star topology and least in case of ring topology i.e. 1.179 Kbits/sec. Packets dropped (24.38 packets) are maximum in case of ring topology followed by star (21.08 packets) and least in cluster topology (16.56 packets). Results also conclude that traffic sent (47.875 Kbits/sec) and traffic received (276.89 Kbits/sec) are maximum in case of cluster topology. Finally he concluded that that cluster topology is more efficient and best suited for the WPAN.

Latre et al (2006) have presented the exact formula for determining the maximum throughput of the unbeaconed version of IEEE 802.15.4 for different frequency bands and scenarios. It was concluded that the throughput varies with the number of data bits in the packet. In the 2.4 GHz band a maximum throughput of 163 Kbps or an efficiency of 64.9% can be achieved. The other frequency bands offer a higher efficiency, but a lower effective throughput. By changing the back off exponent, a higher throughput can be
obtained. It is concluded that the bandwidth efficiency is rather low due to the small packet size imposed in the standard.

Chiara Buratti et al (2009) have provided an analytical model for the non beacon-enabled mode of the IEEE 802.15.4 MAC protocol. A WSN composed of nodes, which transmit data to a sink through direct links, is considered. Upon reception of a query from the sink, the nodes transmit their packets by using the carrier-sense multiple access with collision-avoidance algorithm defined by IEEE 802.15.4. His mathematical model allows the evaluation of the statistical distribution of the traffic generated by the nodes. In particular, the probability that a node succeeds when accessing the channel and that the final sink receives a packet coming from whatever node is derived. The results show how the distribution of traffic changes when different loads are offered to the network. Moreover, the model allows the evaluation of the optimum size a packet should have so that the success probability for its transmission is maximized. The results are validated through simulations.

Marghescu et al (2011) have evaluated the performance of a ZigBee WSN using OPNET. The network is intended for a general application and should be able to collect data from many nodes, every node connected to several sensors. One possible application for such a network is in the medical area. At first the network will be used to display the evolution of blood pressure; the body temperature, the ambient temperature and pressure and the level of the transfusion liquid can be collected as well. The network coordinator will transmit the data to a local server for further processing. The simulation will be used to evaluate the general parameters of the wireless network and to optimize it.
2.4 BEACON ENABLED MODE OF IEEE 802.15.4

In Beacon Enabled Mode, Coordinator periodically sent a Beacon Frame, to synchronize devices that are associated with it, Beacon frame contains Superframe specification. In Beacon Enabled Mode, all the nodes transmit their packet by their allocated time.

Lance Hester (2006) has Performance Study of a Beacon Enabled IEEE 802.15.4 Wireless Sensor Network OPNET Simulator. OPNET simulations of 15.4 WSNs reveal the trade-offs of power consumption with regards to operating in beacon enabled mode or not and variation of device duty cycle by either increasing/decreasing SD or BI. From the simulation results, operating in beacon enabled mode at low duty cycles provides double power savings benefits for a WSN. Beacons are beneficial for devices communication synchronization. They free devices from having to listen to communication channels or send extraneous synchronization messages, both of which sap precious battery life. The synchronization of beacons complements low duty cycle operation where devices operate in sleep mode most of the time and should expend as little as possible current capacity in order to coordinate communication with neighboring devices.

Giuseppe Anastasi et al (2009) have investigated the performance of 802.15.4 sensor networks when power management is enabled. He observed that, even with an ideal wireless channel, sensor nodes experience an extremely low delivery ratio. He found that the MAC unreliability problem is originated by the CSMA/CA MAC protocol, which is unable to efficiently manage contentions for channel access even when the number of sensor nodes is very limited (e.g., 5). The problem can be overcome by choosing more appropriate MAC parameter values, even though in scenarios with a large number of nodes and/or high traffic conditions, the desired level of reliability


can be achieved only by using MAC parameter values out of the range allowed by the 802.15.4 standard.

Petr Jurcik et al (2007) have proposed an accurate OPNET simulation model, with focus on the implementation of the GTS mechanism. The motivation that has driven this work is the validation of the Network Calculus based analytical model of the GTS mechanism that has been previously proposed and to compare the performance evaluation of the protocol as given by the two alternative approaches. Therefore, in this paper he has contributed an accurate OPNET model for the IEEE 802.15.4 protocol. He also proposed a novel methodology to tune the protocol parameters such that a better performance of the protocol can be guaranteed, both concerning maximizing the throughput of the allocated GTS as well as concerning minimizing frame delay.

Koubaa et al (2006) have analyzed the performance limits of the slotted CSMA/CA mechanism of IEEE 802.15.4 in the beacon-enabled mode for broadcast transmissions in WSNs. The motivation for evaluating the beacon-enabled mode is due to its flexibility for WSN applications as compared to the non-beacon enabled mode. His analysis is based on an accurate simulation model of the slotted CSMA/CA mechanism on top of a realistic physical layer, with respect to the IEEE 802.15.4 standard specification. The performance of the slotted CSMA/CA is evaluated and analyzed for different network settings to understand the impact of the protocol attributes (superframe order, beacon order and backoff exponent) on the network performance, namely in terms of throughput (S), average delay (D) and Probability of success (Ps). He has introduced the concept of utility (U) as a combination of two or more metrics, to determine the best offered load range for an optimal behavior of the network. We show that the optimal network performance using slotted CSMA/CA occurs in the range of 35% to
60\% with respect to an utility function proportional to the network throughput (S) divided by the average delay (D).

Anis Koubaa et al (2006) have proposed that IEEE 802.15.4 protocol is flexible communication solution for Low-Rate Wireless Personal Area Networks including sensor networks. It presents the advantage to fit different requirements of potential applications by adequately setting its parameters. When enabling its beacon mode, the protocol makes possible real-time guarantees by using its GTS mechanism. He has analyzed the performance of the GTS allocation mechanism in IEEE 802.15.4. The analysis gives a full understanding of the behavior of the GTS mechanism with regards to delay and throughput metrics. First, he proposed two accurate models of service curves for a GTS allocation as a function of the IEEE 802.15.4 parameters and then evaluated the delay bounds guaranteed by an allocation of a GTS using Network Calculus formalism. Finally, based on the analytic results, he analyzed the impact of the IEEE 802.15.4 parameters on the throughput and delay bound guaranteed by a GTS allocation. The results of this work pave the way for an efficient dimensioning of an IEEE 802.15.4 cluster.

Jelena Misic et al (2008) have described design and performance issues of cluster interconnection for beacon enabled 802.15.4 clusters. His discussion showed that there are pros and cons for both approaches. SS bridge removed the task of bridging from the WPAN coordinator but it generated more traffic in the source cluster. MS bridge efficiently used the inactive superframe period where all nodes sleep and utilizes uplink data transmissions, but it becomes a single point of failure and target for security attacks.

Petr Jurcik et al (2010) have demonstrated the application of Time Division Cluster Scheduling (TDCS) tool for the configuration of IEEE
802.15.4/ZigBee beacon-enabled cluster-tree WSNs using the simulation analysis, as an illustrative example that confirms the practical applicability of the tool. The simulation study analyzes how the number of retransmissions impacts the reliability of data transmission, the energy consumption of the nodes and the end-to-end communication delay, based on the simulation model that was implemented in the OPNET Modeler. The configuration parameters of the network are obtained directly from the TDCS tool. The simulation results show that the number of retransmissions impacts the reliability, the energy consumption and the end-to-end delay, in a way that improving the one may degrade the others.

Hyeopgeon Lee et al (2011) have designed an efficient slotted CSMA/CA algorithm for the IEEE 802.15.4 LR-WPAN. The proposal algorithm using the EBE (Efficient Backoff Exponent) variable decreases the network output load, the energy consumption and the dropped packet, so the data transmission is more efficient than the current standard.

Myung June Youn et al (2007) have presented a novel QoS mechanism in IEEE 802.15.4 CSMA/CA using Gaussian back off time. By using Gaussian back off time which the characteristic of Gaussian random variable is changed as priority of packet QoS or delay and throughput can be differentiated. Also there is no limit on number of priorities because have only to add new Gaussian function for that priority to add new priority. His algorithm did not have change in current hardware, i.e., Gaussian backoff algorithm maintained compatibility with IEEE 802.15.4 standard.

Ranjeet et al (2007) have discussed the performance analysis of IEEE 802.15.4 MAC assuming star topology in the beacon enabled mode. He has obtained an analytical expressions for channel sensing probabilities and saturation throughput during the contention access period. He has included the packet discard analysis and validated the analytical expressions for these
parameters using NS-2 simulation. Further, he also discussed the performance analysis of the MAC when the contention access mechanism of IEEE 802.15.4 is modified to have only one channel sensing. Finally, he discussed adaptation of the frame length for the case with one channel sensing.

Sofie Pollin et al (2008) have proposed a very accurate model for the slotted Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) access scheme of the IEEE 802.15.4 standard for the unacknowledged transmission mode. Because of the design of the 802.15.4 carrier sensing mechanism, modeling the performance of the network in case of acknowledged transmissions is not a trivial extension. He also presented an analytical model for the medium access control layer in IEEE 802.15.4 standard in case of acknowledged uplink transmissions. The validity of the analytical model is demonstrated by the fact that its predictions closely match the simulation results and then use the analytical model to predict energy consumption and achieved throughput of saturated and unsaturated 802.15.4 networks, based on which some design guidelines related to the use of acknowledgements can be derived.

Hui Jing et al (2011) have presented an embedded Markov model to accurately evaluate the performance of Slotted CSMA algorithms for saturated uplink traffic with both ACK and non-ACK modes. Moreover, from the analytical model, he maximized throughput considering the number of devices and the data payload by NLP. Furthermore, according to optimization, he proposed an approximate and simple Markov model to achieve an adaptive backoff for maximal throughput. Finally, comparing with IEEE 802.15.4 Slotted CSMA through the simulation, his scheme improved network throughput with non-ACK and ACK modes. According to the simulation results, his algorithm performed adaptive backoff processing to maximize the throughput. When the number of devices is small, the
probability of sensing channel is increased or vice versa. Moreover, when the number of devices is large, his scheme can obtain excellent performance.

Dongjie Yin et al (2012) have presented a queueing model of the input buffer for the MAC layer of the IEEE 802.15.4 mechanism by using an accurate and comprehensive Markov chain. He used the analytical model to predict the throughput and energy consumption of the networks under non-saturated environment. The exponential backoff scheduling algorithm has been exploited in this model to establish the throughput stability of networks. With the proper selection of $q$, the network throughput of the exponential backoff scheme can always be stabilized. Moreover, the energy consumption of a single node is kept small within the stable throughput region.

Prasan Kumar Sahoo et al (2008) have designed an analytical model for the beacon-enabled slotted CSMA-CA mechanism of IEEE 802.15.4 wireless sensor network. The current mechanism of IEEE 802.15.4 CSMA-CA is extended to include the retransmission limit of the nodes with packet collision probability. A three dimensional discrete time Markov chain model for the uplink traffic of wireless sensor network is designed to analyze the energy consumption and throughput of the node under unsaturated traffic conditions. The energy consumption and throughput are analyzed for different node numbers and data rates to estimate the possible number of nodes for the better performance in terms of throughput.

Mehta et al (2009) have proposed an analytical model to understand and characterize the performance of GTS traffic in IEEE 802.15.4 networks for emergency response situations. He has presented a statistical model for IEEE 802.15.4 MAC to study latency and frame drop rate performances for GTS traffic for emergency response applications with low latency requirements. The analysis focused on a single-hop star network operating in beacon-enabled mode.
Park et al (2008) have presented an analytical model based on a Markov chain to compute the performance of the GTS allocation mechanism in IEEE 802.15.4 standard. Monte Carlo simulations validated the analysis. His theoretical analysis gave accurate numerical results, which were different from the ones obtained in by using the network calculus. He evaluated the stability of the queue size at the network coordinator, the delay to serve a GTS request, and the achieved throughput for different traffic patterns and protocol parameters. He also derived the dependence of the average delay and queue size as a function of the number of requests. Furthermore, they analyzed the achieved throughput as a function of the amount of data packets to forward for each request. They have observed that lower beacon order gives lower delay but ensures a worse throughput because of the higher drop probability. By contrast, higher beacon order increases significantly the average delay and degrades the throughput.

Pollin et al (2006) have provided one of the first analytical evaluations of its MAC protocol for the slotted channel access mechanism in a star topology network. The form of the analysis is similar to that of Bianchi for IEEE 802.11 DCF. The key difference is in the main approximation assumption: Each device’s carrier sensing probability, rather than its packet sending probability, is assumed independent. Also, unlike in 802.11, the slot duration is fixed. Since the channel is not constantly monitored by the stations. The performance predicted by the analytical model is very close to that obtained by simulation.

Tae-Jin Lee et al (2006) have proposed a new analytical model for slotted CSMA/CA in IEEE 802.15.4 WPAN and evaluated its throughput limit. The relatively low throughput limit inherit from the fact that IEEE 802.15.4 mainly targets low power consumption for small WPAN devices rather than high throughput. The model can readily be utilized to evaluate
performance of more energy-conserving slotted CSMA/CA with battery life extension.

Benakila et al (2010) have presented a new device denoted Beacon Aware device, which respects the beacon traffic properties and avoid all perturbations of mesh traffics, thanks to a priority mechanism implemented with some modifications of the CSMA/CA algorithm. In his experimental results, he focused on the channel access mechanism in the CAP period and showed the ability of the beacon aware device to preserve the beacon traffic from the traffics coming from mesh networks.

2.5 MOBILITY

Ekici et al (2006) have discussed about mobility-based communication proposals for WSNs. Mobility based communication can prolong the lifetime of WSNs and increase the connectivity of sensor nodes and clusters. He also introduces a new approach to compute the mobile device trajectories in sparse WSNs where data generation rates of sensors are known. Among the open research problems, real-time solutions that result in low mobile device speeds and cooperation between multiple mobile devices stand out as challenges that have significant impact. The adaptation of proposed solutions to WSNs with dynamic requirements should also be investigated as near-term research directions.

Stevanovic et al (2008) have presented two types of sink mobility comparison based on the observed energy consumption, packet delivery delay and packet loss. Finally, they proved that random sink mobility model provide better performance than predictable sink mobility, especially from the perspective of overall energy consumption and average packet delay.
Harsh Dhaka et al (2010) has performed extensive evaluation, using OPNET Modeler, to study the impact of coordinator mobility on ZigBee mesh network. The results show that the ZigBee mesh routing algorithm exhibits significant performance difference when the router are placed at different locations and the trajectories of coordinator are varied. He also shows that the status of ACK in the packet also plays a critical role in deciding network performances.

Sonal et al (2012(a)) have presented a simulation study to analyze the effects of behavior of a mobile ZigBee node passing through the radius of multiple PANs, is examined using OPNET simulator.

Sonal et al (2012(b)) have provided an analytical performance model for a network in which the sensors are at the tips of a star topology, and the sensors need to transmit their measurements to the hub node so that certain objectives for packet delay and packet discard are met. He first carried out a saturation throughput analysis of the system; i.e., it is assumed that each sensor has an infinite backlog of packets and the throughput of the system is sought. After a careful analysis of the CSMA/CA MAC that is employed in the standard and after making a certain decoupling approximation, he identified an embedded Markov renewal process, whose analysis yielded a fixed point equation, from whose solution the saturation throughput can be calculated. He validated his model against NS-2 simulations. He then showed how the saturation analysis can be used to obtain an analytical model for the finite arrival rate case. This finite load model captures very well the qualitative behavior of the system, and also provides a good approximation to the packet discard probability and the throughput.

Ioannis Chatzigiannakis et al (2006) have investigated the impact of having a sink moving in the network area and collecting data. He has presented a collection of mobility patterns and data collection strategies that
can be employed in applications where the sink is mobile (mostly related to ambient intelligence). The experimental comparison demonstrates the relative advantages and disadvantages and different trade-offs achieved by each approach. The results showed that for applications where time efficiency is not critical it is better to let the sink suffer the burden of traversing the whole network area (as in protocols P1 and P3), since the greater energy savings are achieved in this way. By trading off some energy efficiency the delivery delay can be significantly reduced if a limited multihop approach is used as in protocol P2. For applications that the mobility capabilities of the sink are limited, but can tolerate some loss of information and increased energy consumption, the best approach is to follow a fixed trajectory with multihop data propagation.

Nizhamudong et al (2011) have proposed a Mobile Sink node control method for Wireless Sensor Networks. These Networks are composed from two types of sensor node, one is “fixed node” which is immovable and the other one is “mobile sink node” which is movable. The fixed nodes will form the clusters, and then the Mobile Sink node by using the Nearest Addition Method of TSP (Traveling Salesman Problem) which moves around the cluster center, decides the best rotation of the communication among the clusters, after, it decides the best fixed node to make the shortest distance of communication. The chosen best fixed nodes will transfer its data to the mobile sink node when it reached to them. Moreover the mobile sink node is also capable to sense the possibility of communication of more than few clusters in between, from then it would identify the best path of collecting the data. This method has proved it efficiency by the result of simulation and experiment that he has conducted and it would evaluate the performance of route cost for a mobile sink node.
Niu Jianwei et al (2008) have proposed an efficient routing protocol for ICMSN, which is composed of buffer management and message forwarding. Buffer management consists of two related components: queuing mechanism and purging mechanism. The former determines priority of messages to transmit or discard based on the importance factor, which indicates the QoS requirement of the messages. The latter utilizes a death vector generated by the sink to purge useless messages that have been delivered from the network. Message forwarding makes decision on which sensors are qualified for next hop based on node delivery probability, which synthesizes the meeting predictability to the sink, current buffer state and residual energy and increases the likelihood that the sensor can deliver the message to the sink. His experimental results showed that the proposed routing protocol not only supports the QoS requirement of different content but also achieves the good performance tradeoff between delivery ratio, delay and resource consumption.

2.6 NETWORK SIMULATOR

A network simulator is a piece of software or hardware that predicts the behavior of a network, without an actual network being present. A network simulator is a software program that imitates the working of a computer network. In simulators, the computer network is typically modelled with devices, traffic etc. and the performance is analyzed. Typically, users can then customize the simulator to fulfill their specific analysis needs.

Feng Chen et al (2007) have presented a simulation model for IEEE Std. 802.15.4 developed in the popular simulation environment OMNeT++. Except for the PAN management and security functions, the model implements the majority parameters and functions defined in the specifications. Compared with the existing IEEE 802.15.4 model in NS-2, our model is built conforming to the latest IEEE Std. 802.15.4-2006 and
implements the GTS data transfer mode, as well as an energy model. In the future work, more PAN management functions will be added to support simulating more complicated scenarios, e.g. mesh topology with ZigBee routing. A series of simulations for evaluating the performance of IEEE 802.15.4 in the QoS aspect are running. He integrated the security functions into his model and investigated how the performances are affected by those security mechanisms.

Hammoodi et al (2009) have investigated the performance capabilities of OPNET Modeler in simulating ZigBee WSNs. In general the results presented here show consistency with other software simulators of WSNs. It can be concluded that OPNET has good potential in simulating ZigBee WSNs since it can provide a vast variety of reports and statistics at different network layers (particularly at the MAC layer) for an individual node or for the entire WSN. Further, it was established that ZigBee WSNs are somewhat easier to deploy and configure compared to other WSN simulators. The effect of varying the number of nodes and the use of handshaking on the performance the ZigBee WSN was also demonstrated. However it was found that OPNET ZigBee WSN does not perform well in the physical and application layers since the essential energy and security models are not incorporated in the simulation of the ZigBee WSNs. Potential improvements were proposed to further develop OPNET Modeler to compete with other well-known WSNs simulators. These improvements will enhance OPNET Modeler to cover all aspects of WSNs simulations and investigations for both researchers and network operators.

Egea-Lopez et al (2005) have discussed Simulation Tools for WSNs. His survey provides guidelines to help selecting a suitable simulation model for a WSN and a comprehensive description of the most used available tools. Regarding availability of models, OMNET++, JiST and SSFNet lack of
available protocol models compared to other simulators (specially, NS-2), which increased development time. Attending to the ability to compose models from basic pieces, the component or actor based packages J-Sim or Ptolemy II offer the maximum flexibility. Tools like NCTUns2.0 or JiST allow any, Linux or Java respectively, application to be used in a simulation. This feature greatly increased their possibilities. Specific tools such as TOSSIM, EMTOS or ATEMU are able to simulate real sensor code.

Regarding performance, one can expect better performance from C/C++ engines than from their Java counterparts. However, recent simulators like JiST/SWAN claim to perform better than NS-2 and GloMoSim (in its sequential version). Obviously, parallel simulations should perform and scale better than sequential ones. The tradeoff is a greater complexity of programming. Parallel simulators as GloMoSim (whose goal is performance rather than scalability) can simulate up to around 10,000 wireless nodes. DaSSF parallel tool, whose main goal is scalability, supports network topologies as large as 100,000 wired elements. All the packages provide graphical support. OMNET++, NCTUns2.0, J-Sim and Ptolemy provide powerful GUI libraries for animation, tracing and debugging. All they include the aforementioned features such as inspection, modification of parameters at execution time, etc. OMNET++ and Ptolemy stand lightly up among them. On the contrary, JiST do not include other graphical interface than an event logger and viewer. Current support in NS-2 is the unelaborate and simple trace reproduction Nam tool. Specific tools also provide surprisingly rich GUIs. TinyViz is the TOSSIM visualization tool, an extensible Java application that provides useful debug information. Besides, it can control and drive the simulation elements. Users can develop their own plugins, which listen for TOSSIM events published by TinyViz and perform some action. EmView is a very similar tool, in this case written in C, for EmTos.
Additionally, Ptolemy-II and NCTU NS-2 provide graphical editors very simple to use. The graphical editors of the rest of packages are not that simple, so it is preferable most of the times to use their script-oriented way to create models. We must also point out that there is a clear trend to use native code from actual devices (e.g., TinyOS/NesC) directly in simulations. All specific WSN frameworks have this capability. As a final remark, credibility concerns about assumptions (mainly about radio channel) have been inherited from MANETs. Such concerns lead to complex models. Use of these detailed models may solve these accuracy issues. However, unlike MANETs, such solution limits the scalability of WSN experiments. New algorithms may alleviate this problem. Although, it is an open research field, new advances should contribute to improve scalability. Additionally, modeling problems arise when considering the new environment and the energy components. They also compromise scalability and accuracy. A deep study of these issues is mandatory for a better understanding and characterization of sensor networks and their corresponding simulators.

Andreas Timm-Giel et al (2008) have simulated a simple scenario for WSNs with three different simulation tools: NS-2, OMNeT++ and OPNET. The scenario investigated is that of a fire fighter entering a building and deploying sensor nodes in different rooms. Data collected from the sensor nodes is transmitted to the fire fighter and the incident commander at the other end. The simulation tools are compared regarding their ease of implementing the real time scenarios, collecting the metrics delay, throughput as well as comparability of the results.

Gilberto Flores Lucio et al (2003) have presented a comparative study of two well-known network simulators: OPNET Modeler and NS-2. The accuracy of NS-2 and Modeler from OPNET was compared using CBR data traffic and an FTP session. Several scenarios were evaluated and
regenerated in the simulation tools and the network testbed. The results provided interesting guidelines to network researchers in the selection of network simulation tools.

From the researcher’s point of view, NS-2 provides very similar results compared to OPNET Modeler, but the “freeware” version of NS-2 makes it more attractive to a researcher. However, the complete set of OPNET Modeler modules provide more features than NS-2, and it therefore will be more attractive to network operators. One specific observation can be made about these network simulators as a result of these experiments. For a simple CBR data traffic, it appears that the simulators had no significant problem in terms of accurately modeling the testbed behavior. However, in the case of an FTP session, the simulators using default simulation settings did not adequately model the dynamic behavior of FTP when is used in its basic standard form. FTP (through TCP flow control) adapts its output to prevailing network conditions, whereas the response of NS-2 and OPNET Modeler did not always mimic this performance. However, when “finetuning” of parameters was performed, it was found that Modeler was a more accurate simulator for this particular case.

Stephane Lohier et al (2011) have focused on the results relevance of wireless sensor network simulators in different scenarios based on indoor and outdoor environments. He has proposed a comparative study between 3 usual simulators (NS-2, OPNET and QualNet) while using as reference a real testbed based on recent Imote2 sensors. The simulators give different results even in similar environments. NS2 and Qualnet give results close to those of the experimentation in the case of an indoor environment, but in the outdoor environment Opnet gives results closer to the reality. In addition, the impact of different MAC protocols (B-MAC and TKN15.4 MAC) which observe or do not observe the IEEE 802.15.4 standard is illustrated by real
experimentations. They show that TKN15.4 protocol gives a better throughput than B-MAC.

Jurcik et al (2007) have provided a reference guide to the IEEE 802.15.4 OPNET simulation model. The simulation model can be used for the performance evaluation of the slotted CSMA/CA and GTS mechanisms in beacon enabled mode. The optimal setting of the protocol parameters can be found and verified with this simulation model.

Pesovic et al (2012) have Developed OPNET model of IEEE 802.15.4/ZigBee networks proved to be useful for simulation medium access in real life applications, where presence of hidden nodes in network is invertible. Also model can be used for simulation of cluster-tree topology which is most commonly used because it's much simpler for implementation than mesh topology.

Kumar et al (2012) have given briefly survey on a performance comparison study of the different network simulators for wireless network. There are many simulators for wireless network, but among them five are the popular simulators these are: Qualnet/GlomoSim, OM-Net++, NS-2, OPNET modeler and JSim with a real-world test bed. The paper helps to identify one is best option among shown simulator for their best need. Finally, the paper contains survey, comparative study and conclusion about making the suitable choice of network simulator supporting wireless network based on the numbers of surveys and papers.

2.7 SUMMARY

It is evident from critical review of literature that exhaustive research work has already been done by several researchers to improve the performance of the wireless sensor networks. When the numbers of nodes are
increased in a network, it makes more congestion and it degrades the performance of the network. To avoiding congestion, Beacon enabled mode is preferred. From the above literature OPNET network simulator is the best one to analyze the network, because of its accuracy.