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A Comprehensive Analysis of Literature Reported Mac and PHY Enhancements of ZigBee and Its Alliances

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Abstract: Wireless communication is one of the most required technologies by the common man. The strength of this technology is rigorously progressing towards several novel directions in establishing personal wireless networks mounted over on low power consuming systems. The cutting-edge communication technologies like bluetooth, WIFI and ZigBee significantly play a prime role to cater the basic needs of any individual. ZigBee is one such evolutionary technology steadily getting its popularity in establishing personal wireless networks which is built on small and low-power digital radios. Zigbee defines the physical and MAC layers built on IEEE standard. This paper presents a comprehensive survey of literature reported MAC and PHY enhancements of ZigBee and its contemporary technologies with respect to performance, power consumption, scheduling, resource management and timing and address binding. The work also discusses on the areas of ZigBee MAC and PHY towards their design for specific applications.

Keywords: *ZigBee, MAC and PHY, Interference, Energy, Addressing.*

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I. TECHNOLOGY BACKGROUND

Wireless LAN

John O'Sullivan [1] an Australian electrical engineer led a team of his colleagues, invented the core technology that made Wireless LAN. During 1990's Sullivan and his team developed several techniques for reducing multipath interference of radio signals transmitted for computer networking. This technology has major role in wireless WiFi implementations [2] [3]. The technology has been made part of 802.11a, 802.11g and 802.11n Wi-Fi standards and been patented by CSIRO [4]. Sullivan basically works with fourier transformations applied to radio astronomy. The invention of wireless LAN too is a part of working with fourier transformations. At present he is in the final step of designing of Australian Square Kilometer Array Pathfinder Telescope. Sullivan rigorously worked in development of strong foundation for adaptive optics in light telescopes and redundant baseline interferometer in radio telescopes.

The efforts of Sullivan and his team have given birth to the wireless network communication. The major hurdle lies in standardization of such communication. In the year 1997, Vic Hayes led the IEEE team to standardize the wireless networks, created the 802.11. He is often referred as the father of Wi-Fi who made the network feasible [5]. Several improvements were later done to 802.11 resulting 802.11a, 802.11b, 802.11g, and 802.11n.

Apart from Sullivan and Vic Hayes, prominent researchers associated with CSIRO via. Terry Percival, Diet Ostry, Graham Daniels and John Deane have also taken the major part of inventing the technology [6].

Bluetooth

The technology Bluetooth® is created by Ericsson in 1994 which initially conceived as a alternative to RS-232 data cables [7]. The main intent of this technology is to establish a convenient and secure connectivity between various electronic devices spread within short distances using radio signals. Today it has become an essential element for bringing everyday gadgets into the connecting world. The technology is made available to public access in most of the countries
operates in the unlicensed industrial, scientific and medical (ISM) band at 2.4 to 2.485 GHz. The technology uses spread spectrum, frequency hopping, full-duplex signal at a nominal rate of 1600 hops/sec during transmission.

There is no specific person identified in the development of Bluetooth technology as it involved the efforts several engineers working at Erricsson. A Special Interest Group (SIG) has been established by Ericsson, IBM, Intel, Toshiba and Nokia in the initial phase. Later several companies joined in the group to make the technology widely leveraged in variety of applications. Jim Kardach [8], an Intel engineer working on wireless technologies was in search of a appropriate name for the technology. While reading a historical book he found that second king of Denmark, King Harald Bluetooth was famous for uniting Scandinavia and other allies. Thus he coined the name of the technology as Bluetooth which means a placeholder.

Zigbee

Ember (Presently owned by Silicon Labs) was an American company based in Boston, Massachusetts, USA, developed Zibee wireless networking technology to support companies working in energy technologies. Andrew Wheeler and Robert Poor, the former students of MIT have founded this laboratory in the year 2001 [9]. The idea of self organized wireless network is conceived by Andrew Wheeler during making of TephraNet. He identified that an alternative technology is to be built to observe and analyze many complex systems, for example Ecosystem. Remote sensing satellites and weather stations during early 21st century could not help

the researchers of University of Hawaii to study the rare Silenehawaiiensis plant which grow in the Hawaii Volcanoes National Park, since the details of these plant are too small to be noticed by the satellites. Little bit known about this plant and its habitat because of its isolated geographic location.

A powerful tool that could capture time-series nature of such a plant will help researchers in a great extent. The tool should also be self managing to avoid the barrier of isolated geographic location. TephraNet is the tool developed by Wheeler which will capture the snapshots of the plant at regular intervals. The device is connected to its peer devices forming a wireless self organizing network, transmits the captured long term sensory data back to the collection point. As a safety measure the monitoring devices are made as rocks or branches of trees and are sprinked around the silene habitat. Such networks great helps in monitoring endangered species, battle fields, shipboards etc. Heidemann [10] [11] [12] expressed that advance simulation models aid in retrieving fine details while studying any complex system. But still, actual and accurate input should be provided prior to those models to attain such a goal which could be possible only with help of networking systems like TephraNet. The routing algorithms like GRAd proposed by Dr. Robert Poor [13] inspired the development of TephraNet system.

Fig 1: a) The Silenehawaiiensis plant

Fig 1:b)TephraNet weather Rock

After successful installation and execution of TephraNet, Wheeler and Poor entered into the commercial market and founded the electronics laboratory Ember in the year 2001 with initial $3 million seed financial support from Polaris Venture Partners with DFJ New England, Stata Venture Partners and Bob Metcalfe [14]. The company evolved as a developer of software for mesh networking and stared developing ZigBee complaint chips [15]. The first Zigbee chip EM2420 is released in the year 2003 which was a fully compliant with IEEE 802.15.4 – 2003 standards. Ember has released EM260 Zigbee network co-processor, EM250 system on chip (SOC), and software EmberZNet in the year 2005. Zigbee devices consuming low power are focused by the Ember and started releasing advanced versions of smart energy Zigbee devices from the year 2005. Third generation chips EM300 series are released in the year 2009. All Ember released products conform to IEEE 802.15.4-2003 standards. In the year 2012 the company has been taken over by the Silicon Labs [16].

II. ADVANCEMENTS OF WLAN THROUGH ZIGBEE REPORTED IN LITERATURE

2.1 Studies in focus with improvements of the performance and functionality

The performance of a novel MAC-PHY scheme for wireless local area networks (WLAN) is analyzed by several researchers. Alonso et. al [17] attempted to analyze the performance of MAC-PHY with the intent of improving radio channel utilization using distributed queues and cross-layer concepts. Limitations like back-off periods and collisions occur during data transmissions are been prevented with the use of distributed queues and cross-layer information. Such a transmission performance is expected to be independent of the number of stations transmitting in the system and preserves stability for high load conditions. Apart from these benefits, the cross-layer concept allows the MAC layer to refine its decisions with the feedback response from physical layer. Authors have demonstrated the performance of throughput as a function of different scenario parameters. The work shows a drastic improvement in performance of when using a legacy 802.11 MAC protocol.

Multi-hopping is a technique employed in network routing for preserving guarantee communication. Pekhteryev [18] and his colleagues have developed an image sensor network platform to validate the transmission of images over ZigBee networks which support multi-hopping. Authors have implemented ZigBee networking (NWK) and IEEE 802.15.4 MAC layer protocols on a single M16C microprocessor. Application layer also took the role of transport layer by performing fragmentation and reassembly data packets. This enhanced functionality of application layer is because of lack of fragmentation support in ZigBee network. Multi-hop transmissions of several images of JPEG format are tested in the CSMA/CA access scheme. Statistical results and experimental observations have given solutions to numerous open issues which are also discussed in the work.

The strategy to allow significant number of variable bit rate (VBR) users to share the same bandwidth with different quality of service profiles is an emerging technical issue which has been researched abundantly. Giovanni et. al [19] have successfully exploited the capability of MC-CDMA to support multi-user VBR transmission over multi-path channels using an efficient MAC strategy. Authors have considered an application scenario to assess the performance of the proposed MAC methodology. The radio resources are

selectively attributed to the accessing (transmitting) users based on their performance at MAC. This performance could be measured using an intelligent access point (AP). The allocation of radio channels is done based on the value of AP. For instance, if the quality level is not satisfactory for one or more users then AP issues a low data-rate for such users and increases the number of sub-carriers in order to preserve a lower bit rate with respect to the frequency-selective channel distortions. Authors carried rigorous simulations to obtain the overall system's performance. The proposed approach is found to be promising in both the aspects of performance and flexibility.

Adams [20] presented an introduction to IEEE 802.15.4. His work elucidates the key features of this IEEE standard. His work has discussed in detail about various networking protocols like ZigBee and IPV6 which are being used on top this standard. His work also presented an analysis of the performance of sensor devices employing the technology along with the investigations of power consumption in the standard. The work also presented about the ongoing updates to the standard taking place and brings out certain points in order to make potential products with the help this standard.

Rajeshwaran and Negi [21] have worked out on the ad hoc wireless MAC problem which is a model of interference between links. Pair-wise interference could be treated using disk graph models. These models have been analyzed by the authors to estimate the bounds on MAC performance, with the help of graph theoretic coloring applications. Authors found that the PHY graph model developed during their time is based on the physical layer and so is a more appropriate model than disk graph models. Authors show an initial MAC performance bound based on the PHY graph model. Their work analyzes the model in a novel way resulting in an improved bound on the MAC performance. The accuracy of the PHY graph model is obtained with the support of a thorough simulation experiments. The work found to be promising in terms of performance improvement.

WiFi can use the ZigBee unlicensed 2.4 GHz Industrial, Scientific and Medical (ISM) operating band for its communication. This means that several ZigBee and WiFi devices may run in the same network environment resulting poor performance. In this connection, the clear channel assessment (CCA) is performed by both ZigBee and WiFi devices before transmission according to three different modes which are defined in the standards. Zeghdoud et. al [22] have worked in obtaining the performance of different CCA modes used by both ZigBee and WiFi devices working in the same network environment. Authors inferred that the performance of ZigBee could be optimized by selecting appropriate CCA mode based on the interference level at the receiver.

There are certain limitations encounters while using ZigBee network. Zigbee system operating in 2.4 GHz band mostly works in a closed environment with the characteristics of dense multipath. Multiple access interference (MAI) between terminals within terminals is a crucial parameter to be considered during setup of a Zigbee network. The low MAI gives better performance and in this regard CSMA-CA protocol should be employed for channel multiplexing to avoid MAI while establishing a ZigBee wireless communication system. HouMenget. al [23] have presented a composite expression of such an interference. This expression has a major significance in obtaining the performance of a ZigBee system especially in configurable logical devices (CLD) because of both MAC and PHY layer parameters are synthesized.

The concept of clustering of sensor nodes is followed to support high scalability and better data aggregation. These clusters are made disjoint and non-overlapping. The hierarchical wireless sensor nodes structure helps in limited utilization of power and thus increases the network lifetime. Kumar et. al [24] have analyzed cross layer (MAC/PHY) approach for clustered wireless sensor networks. They have termed the clustering protocol as LEACH, which stands for Low energy adaptive clustering hierarchy protocol. Another protocol called DYMO i.e. Dynamic MANET on-demand is also devised as a routing protocol intended to analyze improvement of clustered approach compared with non-clustered WSNs. Based on the parameters like average jitter, end to end delay, throughput and total charge consumption for different % of duty cycle, authors inferred that the newly developed algorithms could improve the performance of the network.

In certain cases, routing in wireless sensor networks is a little bit complicated compared to other networks via. cellular and mobile ad-hoc networks, because of their special features like scalability, resource management etc. The prime use of sensor nodes is that they are capable of remotely deployed, and areoperated autonomously in unattended environments running on low battery power. Kumar and Tiwari [25] enhanced their earlier research work [53] of analyzing cross layer (MAC/PHY) approach for wireless sensor network scenario with different routing protocols like AODV, DYMO and XMESH subjected with varying percentage of duty cycle (DC). The aim of authors is to obtain the relationship between routing protocols and the % of duty cycle to achieve improvement in routing performance. Parameters like energy consumption during transmit, idle and received mode are computed during the process.

Qing and Guixia [26] have presented an innovative interface design. The design comprised of field programmable gate array (FPGA) implementation intended for transparent transmission between medium access control (MAC) layer and physical (PHY) layer. Authors have introduced a mechanism during the interface design in which the co-processing is performed in CPU and FPGA in order to achieve improved performance compared to other traditional interface architecture. A mechanism of using enhanced memory architecture which includes memory separation and co-operation of different types of memories is employed. The design is executed on the intellectual property (IP) processing core technology subjected with high throughput, low latency and low complexity. The proposed interface has been implemented on Xilinx Virtex FX130T FPGA which is primarily works on Gigabit throughput. The logic employed to design the interface is implemented and the results proved that the logic can attain a maximum throughput upto 3.93Gbps and work on an average of 1.02 Gbps.

A detailed discussion on IEEE 802.15.4 is presented by Mantriet. al [27]. IEEE 802.15.4 operates on three

frequency bands via.868 MHz, 915 MHz and the 2.4GHz unlicensed industrial, scientific and medical (ISM) band. Authors discussed the implementation of the physical layer at 2.4GHz band using Offset Quadrature Phase Shift Keying (OQPSK) modulation using Direct Sequence Spread Spectrum (DSSS) technique. The work is also analyzed for its performance under AWGN channel, Rayleigh and Rician fading channels. Implementation part of the proposed work includes the design of transceiver, whereas, the analysis of performance analysis is carried by comparing bit error rate (BER) of the transceiver with signal to noise ratio (SNR) for AWGN through Rician fading channels.

MAC protocol synchronizes sensor nodes in ZigBee IEEE 802.15.4 Wireless Sensor communication medium. Although MAC is equipped by a set of strengths, still, MAC suffers from several limitations that could result in deteriorating its performance. In a real environment, 80.15.4-based networks are usually communicates in the bounds of other wireless networks that operate in the same ISM band. Therefore MAC of 802.15.4 MAC should be enhanced cope with interference from other networks. This is the reason behind to put efforts in improving MAC for WSNs. Khanafer et. al [28] provided a survey for these protocols and elicited the methodologies they follow to improve the performance of the IEEE 802.15.4 MAC protocol.

The applications of ZigBee is rapidly increasing and are especially seen in smart grid applications like automatic metering, demand response, load control, power fraud detection, fault diagnostics, and distribution automation. Bilgin and Gungor [29] evaluated the performance of ZigBee network in terms of network throughput, end-to-end delay, energy consumption, and packet delivery ratio subjected to variety of smart grid environments which include an indoor power control room, an outdoor 500 kV substation environment, and a network of transformer vaults mounted underground. Based on the performance evaluations of the proposed work, it is found that the ZigBee is ideal to use for smart grid applications which use low-power and low-data rate and which don't require high reliability requirements and real-time deadlines.

2.2 Studies in focus with energy management

Resource management algorithms primarily focus on scheduling and allocating resources in a system. These algorithms results in poor performance if they are running with single layer protocol stack. Zhang and Ben [30] have proposed a joint MAC-PHY layer resource allocation algorithm which optimizes the bandwidth and power allocation with the help of an integrated design of packet scheduling, subcarrier allocation, and power control. Based on the analytical and numerical analysis, authors have concluded that the quality of service rendered by proposed method is same that is observed in wired channel. The efficiency of power and performance of the system is significantly improved compared with traditional systems where resources are allocated based on a strict layering architecture.

The investigations of energy consumption in IEEE 802.11 have been carried by Hoefel [31] and his team. They have developed a joint medium access control (MAC) and physical (PHY) layer analytical cross-layer model and observed the energy consumption in IEEE 802.11 wireless local area networks (WLANs). The work has presented a comparison between numerical and simulation results over the setup of IEEE 802.11a PHY layer.

Bertin [32] and his colleagues at One-RF Technology, Sophia-Antipolis, have developed a novel wireless communication protocol termed as Optimization of Communication for Ad hoc Reliable Industrial network (OCARI). This wireless sensor network technology focuses on applications running in harsh environments like power plants and warships. This network protocol with the intent of improvement in network lifetime supports mesh topology and provides a deterministic MAC access for time-constrained communications as well as energy efficient communications. OCARI supports ZigBee APS, APL primitives and profiles following the standard of PHY layer of IEEE 802.15.4 to preserve compatibility of existing applications.

In order to achieve low power consumption for ZigBee devices, the IEEE 802.15.4 MAC layer operates duty-cycles operations by setting two system parameters via. macBeaconOrder (BO) and macSuperFrameOrder (SO). A comprehensive analysis is carried by Yu Kai Huang et. al [33] to study IEEE 802.15.4 duty-cycle operation. Authors have developed a novel analytical model that accommodates a general traffic distribution. Their work presented an NS-2 based simulation model, which is validated by the developed analytical model. Authors have elicited some important performance-evaluation insights based on the experiments conducted by the analytical and simulation models. These inferences could be used as guidelines for future low-power ZigBee network deployment.

The broad market prospect of ZigBee is for its reliability, low cost, low complexity and safety compared to other wireless network communication protocols. Hong and Zhang [34] analyzed the function of MAC layer in IEEE 802.15.4. In a Zigbee chip, these authors have introduced the process of designing hardware and software co-design of MAC controller to reduce the cost and power consumption.

Of the late, cross layer modeling found to be one important research issue in the 802.15.4 standard MAC and PHY. Biswas et. al [35] have presented a discussion on MAC and PHY layer energy modeling in beacon enable mode for ZigBee network. Authors have considered the dual hop transmission model using DF relay for the proposed work. In this proposed energy model authors primarily focus on the effect of super frame structure along with other MAC layer parameters.

Fourty et. al [36] presented a global study on energy considerations focusing to apply the work on IEEE 802.15.4 technology. Several experiments have been carried out on the prototype of network node which is powered by Lithium batteries in connection with identifying the lifetime of this network element, in different scenarios including 802.15.4 coordinator or end device configurations along with non-802.15.4 protocols. The energy consumption and life time of the battery is clearly dependent on the node receiving state time in turn has a big dependency on not only the network performance like throughput and latency but also the overall energy consumption budget of the battery. Authors have illustrated the non-linear characteristic of the battery capacity.

Authors figured out certain drawbacks which may be avoided in the future design of MAC (Medium Access Control) protocols to maximize node lifetime.

Energy source is one of the key factors for inhabitation of life. Building up of an energy source poses several issues in many aspects of modern life. The same fact could be applicable when addressing portable electronic devices operation. This is because portable devices, which are treated as the evolutionary invention of man during last quarter of 20th century, mostly rely on old battery technology as a source of energy. This fact is still true for many autonomous electronic devices and is of key factor when addressing Wireless Sensor Networks implementation. The simplest and economic feasible energy source for a Wireless Sensor Network node is a battery. However, batteries have a number of drawbacks which become serious limitation when implementing portable or wireless mobile systems. Alternative for conventional batteries is therefore an important topic of both academic and industrial scientific work. Amaro et. al [37] rigorously worked on the execution of Wireless Sensor Network node subjected to a complex communication protocol running on harvested energy with the intent of observing the implications of software related issues.

Sunghoi Park et. al [38] proposed a Smart Energy Management System (SEMS) which works as a controller with the help of a motion sensor and setting time of power usage. The work is primarily targeted to reduce power consumption. The proposed SEMS not only supplies power as the way conventional power strips do but also controls sockets of the SEMS using ZigBee wireless communication. The experimentation is carried with the help of a test bed which is comprised of a motion sensor, the SEMS and three appliances which are connected to the SEMS. The experimentation was carried for five days to study power consumption of three appliances with regard to both functions. The proposed work found that the power consumption of the SEMS with two functions was significantly reduced when compared with the power consumption of the traditional power strip.

The limitations of IEEE 802.15.4, especially interference and power management are been improved in IEEE 802.15.6 Wireless Body Area Network (WBAN). In this enhanced standard, several access modes and access methods are combined with new power management schemes. These refined configurations and newly supported four kinds of data rates determine energy efficiency of the complete WBAN system. Power efficiency is one major enhancement in this standard which improved the quality of service (QoS) in WBAN. Such improvement is extremely helpful in certain critical applications like medical applications with implanted devices. Yanqing Ai and Chiu-Sing Choy [39] proposed a method to decrease the power consumption supporting with the current standard. Authors have also developed an analytical model to evaluate power efficiency. The transaction transfer in higher data rate show good power efficiency during simulation of proposed experimentation. The processing unit which is embedded saves node energy for most applications where the payload is higher than 70 bits per beacon period. Finally it is concluded that when the compression factor is bigger than 2 and node's power consumption does not go beyond 40% of the transceiver, better energy efficiency always can be assured by processing unit insertion.

The rapid success of Internet and the Wireless Sensor Networks led to develop applications in numerous fields, ranging from defense to societal applications. The only commonality in these devices is that they of battery powered and are standardized on communication protocols. Therefore these networks must be carefully designed in order to optimal use the power consumption. Luca et. al [40] designed and validated a new MAC protocol which is able to significantly reduce the power consumption and compliant with the IEEE 802.15.4 standard. The newly defined protocol cleverly configures the node's duty cycle as a function of the transmission times of the neighbor nodes. During a duty cycle period, each node wakes up once to send and *N* times to receive, where *N* represents the number of neighbors, while it remains in hibernation for the remaining time. The proposed protocol is tested using an analytical approach and through simulative approach. In the analytical approach, the devised solution is compared with another literature available energy-efficient protocol, namely AS-MAC. Analysis has been done on the obtained differences of the two approaches. Later the work analyzed the differences between the simulated scenario and the analytical approach using Omnet++ simulator. The performance comparison between proposed protocol and the existing MAC protocol compliant with the ZigBee standard is presented. Based on the results, it is identified that newly proposed protocol is effective, flexible and efficient. The work is able to provide high energy savings at variable date rate, without compromising on packets transmission.

The standard IEEE 802.15.4 has given a widely accepted solution for devising low-cost and low-power wireless communications, and the standard could be applicable to several WSN application scenarios. Several CSMA/CA schemes based on 802.15.4 standard have been proposed in the literature with the intent of enhancing energy efficiency and throughput of sensor nodes. Because of lack of efficient energy backoff management, these networks still suffer from unnecessary waste of energy and bandwidth. Kyoung-Hak et. al [41] proposed a refinement to existing schemes, called *adaptive collision resolution* (ACR) to overcome these limitations. ACR computes the *backoff exponent* (BE) upto the appropriate in the current network contention level with the help of physical and link-layer measurements. Estimated time remaining until idle is leveraged to adjust *backoff periods* (BP) to remove useless backoffs and extra *clear channel assessments* (CCAs). The proposed work is validated through mathematical analysis and tested on the Matlab and USRP/GNU Radio testbed. Authors also performed simulation study using OPNET and found that ACR is promising in holding improved energy efficiency and throughput performance compared with existing schemes.

Bill et. al [42] proposed a novel centralized hardware fault detection approach using Naïve Bayes framework. This work is intended especially for a structured Wireless Sensor Network (WSN). Power supply could be the major hurdle in most of the WSN because they are running on battery only. Network's life is directly dependent on battery life. The proposed Centralized Naïve Bayes Detector (CNBD) analyzes the network end-to-end transmission with the intent of increasing the network's life. In the proposed method,

computation will be shared between the sensor nodes so as to reduce the payload, thus reducing the burden to the battery at the node's battery. The work is evaluated on a WSN of 100-node subjected to various network conditions and varying number of faulty nodes.

Researchers predict the future of Internet might be equipped with billions of battery-powered radio-enabled devices. Most of them may require communicating with each other using Internet gateways (border routers) over multi-hop links. The standard IEEE 802.15.4 radios are proved to be efficient compared to earlier standards still enhanced IEEE 802.11 is preferred despite its potentially higher energy consumption. The situation could be explained with the support of several use cases. Vukadinovic et. al [43] extended the IEEE 802.11 power saving mode (PSM) to save energy. This extension allows WLAN devices to get into a low-power doze state thereby saving energy. The proposed design works as a traffic announcement scheme to facilitate multi-hop communication. This scheme guarantees that all the intermediate nodes are in active state to receive and transmit the pending data frames with minimum latency by propagating traffic announcements along multi-hop paths. The proposed work is simulated and found that Multi-Hop PSM (MH-PSM) improves both end-to-end delay and doze time compared to the conventional PSM. This situation optimizes WLAN network requirements of radio-enabled devices connected over the Internet. The proposed scheme is feasible to construct and implement and doesn't require modification in the existing MAC of 802.11 which is normally implemented on chip. Authors implemented MH-PSM as a part of a WLAN driver for Contiki Operating System. Contiki Os is a specialized operating system designed for resource-constrained Internet of things devices. Authors successfully demonstrated the efficiency of the proposed scheme experimentally.

Pathak et. al [44] proposed an energy efficient wireless telemonitoring scenario especially to benefit cardiac patients through ZigBee. The method is based on variable duty cycle being associated with sensors. For instance, if had a insight in an intra hospital where telemedicine mechanism is employed, Electrocardiogram (ECG) signals of patients are captured are preserved in a Personal Digital Assistant (PDA) at nursing station through. These signals are been transmitted within ZigBee network finally reach to Doctor's PDA. The total network life time could be increased if avoided the energy usage during idle mode. Therefore the number of active sensors should be made dependent on variation of duty cycles. The proposed work comparatively studies the energy efficiency of ZigBee sensors with percentage variations of duty cycle subjected to the energy consumption parameter at variable load conditions. The comparison analysis prepared several matrices with the details of energy consumption at different loads. These matrices are used to evaluate performance and energy consumption in transmit mode, received mode idle mode respectively using Qualnet 5.0.2 simulator.

2.3 Studies in focus of throughput, quality and effectiveness of data transmission

Numerous short range applications have been evolved over the time using low cost, low energy, low transmission rate of 20~250 kbps and often bounded within 10 meters of diameter. These features belong to 802.15.4 LR-WPAN specified in the lower layers of ZigBee through MAC and PHY layers. Of the late, the voice transmission over this standard is quite improved. Eunchanget. al [45] carried experiments to study the possibility and effectiveness of voice transmission in a ZigBee environment. Authors have used ns-2 simulator and performed thorough simulations and provided several use cases as its applications with the help of their implementations.

The IEEE 802.15.4 standard is potentially vulnerable to interference by other wireless technologies working in 2.4 GHz operating band such as IEEE 802.11 and Bluetooth. The performance is drastically degraded with the increase of wireless devices share a common radio channel to communicate between devices, resulting multiple hidden-node collisions occurs for CSMA/CA channel allocation. Mohana and Radha [46] proposed a solution to the hidden-node problem. They have incorporated the handshake signals to the existing MAC protocol which could enhance the performance of data transmission.

The design and implementation of a novel MAC-PHY interface (MPI) protocol is pursued by Wang et. al [47]. Their work is based on peripheral component interconnect express (PCIe) bus and field programmable gate array (FPGA). The proposed MPI architecture produces a transparent, reliable, high-rate, low-delay, and better communication between medium access control (MAC) layer and physical (PHY) layer with the aid of high-performance FPGA and high-speed bus PCI. MPI is aimed to reduce the burden by considering certain functions of the central processing unit (CPU) for MAC layer and FPGAs for PHY layer. The proposed architecture has leveraged more resources for processing mass data and complex algorithms, and thus will help systems achieve gigabit-per-second (Gbps) throughput require in the next generation wireless local area networks (WLANs). The proposed MPI protocol is implemented on Xilinx Virtex-6 LX130T FPGA and is executed on a very high throughput (VHT) WLAN testbed system. Experimental results under indoor environments revealed that the proposed MPI architecture could attain a throughput of 1.21Gbps.

Maryam et. al [48] proposed a cross-layer algorithm for the down link multiuser orthogonal frequency division multiplexing (OFDM) system. The aim of their research is to ensure fairness among users along with the preservation of full system throughput as close as possible to the system throughput maximum limit. Authors have devised a formula of function to designate which packet will be scheduled at any given time. This proposed function considers the parameter from the physical layer and MAC layer. With the intent of a good service to a user, at the physical layer the other users should never be disregarded. The proposed cross layer algorithm is subjected to certain prerequisite requirements like the knowledge of channels state information and the state of the queues. The proposed algorithm and the overall scheme based on the simulation results show a near-optimal performance for the average system throughput and give a good fairness among users, while taking a relatively low complexity.

ZigBee builds upon IEEE 802.15.4 low-rate wireless personal area standards networks may seems be secured

through 128-bit encryption keys and by MAC address access control lists. Still, these measurements are found to be vulnerable to interception and spoofing techniques and tools which are freely available over the Internet. To prevent these limitations, Ramsey et. al [49] have proposed a multi-factor PHY-MAC-NWK security framework for ZigBee transmission that appends bit-level security with the aid of radio frequency (RF) PHY features. These RF (PHY) features are also called as RF fingerprints are used to differentiate between wireless devices based on their dissimilarity or likeliness. The research works presented in the literature prior to this research work are mostly PHY-based and works on mesh network device differentiation predominantly captures the signal turn-on region, measured in nanoseconds. The proposed work shows a PHY-based reliable discrimination at SNR $\geq$ 8 dB subjected to a classification accuracy of 90% or more. The mechanism is performed using the entire transmission preamble, which is of fewer complexes to detect and is 1000 times more than the signal turn-on region. The proposed work introduce a statistical, pre-classification feature ranking technique to identify relevant features that unexpectedly reduces the number of RF fingerprint features without compromising the classification performance.

ZigBee is found to be the most prominent networking alliance dedicated to low-power embedded system. Jian et. al [50] attempted to work on PHY and MAC layer protocols based on the specification of IEEE 802.15.4. Authors discussed the details of the IEEE 802.15.4 MAC layer protocol, well particularly the slotted CSMA/CA algorithm. Authors have computed the average transmission delay within the network. Finally they have proposed an improved algorithm of the average transmission delay time. The result of their work is compared with the original algorithm and illustrated various simulation application scenarios.

Park et. al [51] proposed a cross layer technique to improve the quality in video streaming during wireless communications. They have considered application (APP), medium access control (MAC), and physical (PHY) layers together in order to attain the objective. The proposed technique follows modulation coding schemes (MCSs) of MAC layer and uses source significance information (SSI), error concealment unit of APP layer, and channel quality information (CQI) of PHY layer. Authors demonstrated the improved video quality in Rayleigh fading wireless channels using the proposed cross layer technique. The demonstration is performed using streaming of H264 videos.

In a high end-to-end channel, special amplification mechanisms are employed. For instance, the amplify-and-forward scheme multiple-hop MIMO relays system is taken into account in order to communicate in a high-to-end channel. In such a communication, the distance between the transceiver and receiver along with the transmission power at each relay are optimized in order to cope with the bottlenecks and thereby assure a high end-to-end channel capacity. Pham et. al [52] have proposed a transmission environment coefficient which guides in choosing a new way when loss of path is encountered. This coefficient also helps in optimizing the distance of multiple-hop relay system in a simple manner. If the system has no control over MAC layer, the performance might poor due to presence of interference. The proposed multi-hop system reduces the interference signal in turn increases high end-to-end channel capacity.

The transmission of videos in 802.11 wireless networks poses many challenges. Two major challenges encounter in real time video transmission over wireless include bandwidth demands and timing constraints. The cross layer design found promising to increase network throughput as well as overall network capacity. Kalshetti and Koli [53] have explored one of such design approaches that include physical (PHY) and medium access control (MAC) layers considerations and have proposed a new scheme for optimizing the wireless network's MAC and PHY layer parameters. They have presented a detailed survey of MAC and PHY layer considerations for an improved video transmission performance. The best solution for the issue of real time video transmission is pursue a comparison analysis of different methods of adapting parameters in order to achieve delay constraints in real environment. Authors explored the best techniques in the literature which are best suitable for real time video transmission. The study carried by the authors focuses on adaptive retry limit (ARL) parameter for MAC layer and PHY layer parameter like Enhanced Adaptive Forward Error Correction (EnAFEC) mainly intended for real time video transmission over a wireless network.

Kazemian and Quazzane [54] presented Neuro-Fuzzy applications of Moving Picture Expert Group (MPEG-4) video transmission in IEEE 802.15.4 ZigBee wireless standard. The limitation of interference in ZigBee is again considered by the authors for the proposed solution. Video transmission requires large bandwidth and may result in data loss and time delay in ZigBee channel because of high variation in bit rate. This limitation is much more serious that almost impracticable for MPEG-4 VBR video to be transmitted in the ZigBee channel. The proposed work of authors introduced two new Neuro-Fuzzy schemes to monitor the input and the output of a data storage which is acting as a traffic-regulating buffer. The input of the buffer is monitored and coordinated by a Neuro-Fuzzy scheme to ensure that the traffic-regulating buffer neither flooded nor starved while video transmission. The output of the traffic-regulating buffer is monitored by the second Neuro-Fuzzy scheme to ensure the video transmission departure-rate conforms to the traffic condition of ZigBee. Extensive simulation results demonstrate that the proposed two Neuro-Fuzzy schemes improved improve the picture quality by reducing the excessive data loss. The work is compared with the conventional MPEG-4 VBR video transmission over ZigBee.

The standard IEEE 802.15.4-2006 is identified as widely used standard for multi-hop wireless sensor networks. The standard employs tree structure in its MAC layer, which may results in network failure or link failure. However this standard makes use of a tree structure in its MAC layer, which may result in either node failure or link failure. Along with this limitation, the single path approach may also lead to poor routing since its selects next node by its own criteria. The scheduling of transmission should also be made appropriate to avoid collisions. Bogdan et. al [55] proposed the modified cluster-tree structure into a Cluster-Directed Acyclic Graph (DAG) to improve the robustness. The proposed method also

looks into the topology redundancy at the MAC layer level. A greedy algorithm is associated with the proposed method for scheduling compatible with the IEEE 802.15.4 MAC mechanisms. Extensive simulations show that proposed mechanism improves the performance of MAC layer for multi-hop topologies. The revised routing protocol (RPL) is found to exploit the cluster-DAG and thereby reduce the packet loss. This improvement also has a profound impact in energy saving with the reduction of number of transmissions.

In WSN, throughput is one of the significant parameter to determine the quality of service of the network. Packet loss is the major hurdle which degrades throughput of the network. This packet loss issue is more in WSN, since nodes are located randomly. Interference, packet collision and failure of intermediate nodes are the three major factors responsible for packet loss in WSN. Interference occurs due to co-existed networks working in same frequency band. Co-located networks lead to collisions. Failure of nodes may be because of overload. Rambabu et. al [56] proposed a solution to solve the problem of packet loss which is caused due to overload of the intermediate nodes. To avoid overload at the intermediate nodes, the proposed routing algorithm works based on the remaining energy at the intermediate nodes. This proposed methodology is termed as Remaining-energy based Adaptive Multi-hop Algorithm (RAMA), which makes the routing decision obtaining the remaining energy at each of the neighbouring nodes. Once the remaining energy is estimated then algorithm finds out the short distance multi hop communication to relay the data from source node to sink node. Authors implemented the proposed algorithm on TI wireless sensor nodes. The performance of the work is compared with the performance of SimpliciTI protocol. Extensive experimentation inferred that a 27% improvement in the throughput is achieved with the proposed algorithm RAMA.

Cheng and Ho [57] with the intent of robust transmission have proposed a multi-channel ZigBee wireless sensor network (WSN). The packet delivery ratio (PDR) is focused to increase this proposed method through the application of multi-channel technology. Authors using hardware devices have implemented a multi-channel time division multiple-access scheme which will work based on a cluster-tree construction protocol. Keeping in mind about the issue of interference with ZigBee and WLAN, authors, developed an interference avoidance method which decreases the impact of interference between ZigBee and WLAN. Authors further evaluated their proposed method using a practical network implementation to obtain the resulting performance. Experiment results reveal significant improvements in the PDR of ZigBee transmission in a networking setup with interference from WLAN.

2.4 Studies related to address and timing management

The PHY and MAC specification given by IEEE for ZigBee alliance supports both tree and mesh networks. No routing table is needed if tree topology is employed. This technique led to revolutionary benefit in business network. However, one limitation still exists with the standard i.e. maximum length of the network is 16 hops and in most of cases the network can't be scaled to increase. This is because of the exhaustion of network address in some portion of network while the other portion of network is poorly loaded. Giri and Uttam [58] [59] have have presented a solution to this limitation. They have presented a unified address borrowing scheme which can be easily applied to grow the network beyond 16 hops. To overcome the network address exhaustion problem a technique is employed to borrow address within the network. Authors have extended their work and further presented a unified address reorganizing scheme which can be easily applied to asymmetric tree network.

The mechanism of borrowed address algorithm can reduce the number of orphan nodes in ZigBee networks that use distributed address assignment mechanism (DAAM). Conventional borrowed address algorithms could increase the success rate of address assignment, but still they pose serious issues like greater cost of overhead and time in searching network caused by breaking topology. To solve such issues, Yao et. al [60] proposed an improved and efficient distributed borrowed address assignment algorithm which is associated with a topology maintenance function(A2BTM). This function initially borrows address from the child nodes in the same branch for the orphan nodes and propagates the borrowed address message immediately within the network in order to decrease the overhead and time spent on the mechanism of borrowed address and thus maintains topology. The proposed work is evaluated by both theoretical and simulation experimentation. Analyses based on extensive experimentation figure out that A2BTM algorithm much more promising than DAAM and its improved algorithms in terms of the overhead and time spent in searching network, on the hypothesis of preserving a higher success rate of address assignment. The proposed work also could lessen the impact from detour phenomenon efficiently.

Medina et. al [61] discussed the issue of accurate time synchronization of wireless sensor networks (WSNs) used in applications where a physical phenomenon must be governed through periodical sampling. Incorrect time synchronization can predominantly degrade the system precision in certain applications like local positioning systems (LPSs) using ultrasonic time of flight (TOF) measurements for pseudorange estimation. Drifting of clock and the dynamic variations of the start time used in each measurement are the two main error sources to synchronize the time at each node. In the proposed work a Time Division Multiple Access (TDMA) synchronization algorithm is presented to avoid these issues for WSN using the IEEE 802.15.4 ZigBee standard. The algorithm is able to handle the mentioned error sources in an effecient and effective way. Experimental results proved the effectiveness of the proposed work with an implementation of an ultrasonic pseudorange measurement system between wireless nodes.

Timing is a major issue in most of the wireless, lower-layer (e.g., physical and data link layer) communication protocols. As the complexity of MAC protocol increases, the maintenance of time-critical behavior is a serious challenge for several MAC implementations. Existing MAC implementations normally require a strong integration to the radio driver to attain strict time constraints. In a normal scenario, the integration seems to be monolithic block of code with MAC-specific logic hard coded at low firm level. The

association of time-critical functions in the firmware is good idea, but this results in poor flexibility for MAC designers since the radio driver is strongly dedicated for specific MAC. Pieter et. al [62] proposed "snapMac", a generic MAC/PHY architecture with a neat separation between the MAC and radio firmware level. The proposed generic programming interface brings out more flexibility, a simple way to compose new MAC designs, and getting response from the radio capabilities. Authors demonstrated the simplicity and performance of the proposed architecture by implementing it on a resource-constrained wireless sensor node. The flexibility of the software along with its timing constraints are found compliant to IEEE 802.15.4 based experimental evaluation. Authors obtained 97% of throughput theoretically. The same idea could also be employed to other domain like WiFi, cognitive radio etc. Portability could be one important feature to be added to snapMac in future research. The generic snapMac "snapMac" in a snapshot could enable the design and execution of new MAC protocols.

Broadcast and convergecast are considered as the most happening basic operations executed simultaneously in a wireless sensor network. Literature reported works have proposed various solutions for energy-efficient and low-latency scheduling. Most of these works have given optimal solutions for one-way scheduling (broadcast or convergecast). Attempts have been done by Lun and Meng [63] to define a low-latency two-way beacon scheduling (LTBS) problem for ZigBee tree-based networks. In their work, beacon represents the timing of nodes to deliver broadcast and convergecast traffics. Authors categorized this problem as slot assignment problem in which each node needs to get slots for both upstream and downstream transmissions during the process of avoiding interferences. The work proposed two efficient slot assignment algorithms using the concept of sequencing nodes' slots to enable two-way traffics. The work revealed several benefits of the proposed schemes using extensive simulations. Finally authors inferred that the proposed algorithms could attain improved low-latency in ZigBee networks.

Security with respect to energy saving should be one of key issues in establishing a large-scale wireless sensor network (WSN). Traditional network configuration mechanisms may not cater to the mark in working energy inefficiency and/or addressing failure issues especially in large-scale WSNs. Hyung et. al [64] considered this issue as a distributed addressing in WSN. Authors designed an improved network configuration which allows each router to work with its own addressing space for obtaining unique address to its offspring. Authors devised another algorithm to select the type of the node (router or end device) which scans the entire network in reduced number of hops to save energy. The proposed mechanism strongly supports the network connectivity in a distributed manner by conforming at least one neighboring router for each node. The work is evaluated by thorough simulation experimentation for its performance. Performance is found improved compared to other conventional schemes when the work is applied for large-scale WSNs.

The issue of coexistence in WLANs leads to poor response time while accessing with home control applications. Hong et. al [65] proposed a method to control the WLAN traffic. In this method, ZigBee transmissions should be controlled such that the maximum tolerable delay should not be met due to the WLAN interference. Authors focused to assure that the delay experienced by ZigBee sensors like alarm signals would not exceed the maximum tolerable delay and at the same time the network is maintained as high throughput as possible in the WLANs. The proposed study is simulated for evaluation and results concluded that the proposed algorithm can improve the delay performance of ZigBee networks based on the mitigation effect of WLAN interference and thereby improve the throughput in the WLANs.

2.5 Studies related to the issues and solutions on interference of co-existence networks

Collocated networks running the same frequency bounded in commercial and residential buildings often results interference. This phenomenon sometimes may look severe depending on the applications working. Wenqui et. al [66] focused to elicit the issues affecting co-existence of IEEE 802.15.4 (ZigBee) systems occurred due to interference. Since, ZigBee standardized on the IEEE 802.15.4 PHY and MAC layer to handle devices, the practical performance of ZigBee systems could be estimated either empirically or by simulations. Authors have carried simulation experiments and found that, among different interferers, interference from microwave ovens is seems to be a major problem. Finally authors have provided guidelines for installing sensors within commercial and residential buildings.

Day to day the unlicensed ISM spectrum is becoming crowded by wireless local area network (WLAN) and wireless personal area network (WPAN) users and devices. Spectrum sharing within the same network of devices could be handled by standardized MAC protocols, but still the coexistence between WPAN and WLAN (e.g., ZigBee and WiFi) is considered as a challenging issue. The conventional MAC protocols are poor in dealing with the disparate transmit-power levels, asynchronous time-slots, and incompatible PHY layers of variety of interconnected heterogeneous networks. Contemporary research studies focused on measuring moderate-to-high WiFi traffic and the severity of impairment in terms of performance of coexisting ZigBee. Xinyu and Shin [67] proposed a novel mechanism, called cooperative carrier signaling (CCS), harmonizes coexistence Zigbee devices with WiFi WLANs by exploiting the implicit cooperation among Zigbee devices. A separate Zigbee device is allocated to emit a busy tone indicating the carrier signal simultaneously with the desired ZigBee's data transmission, resulting enhancing the ZigBee's visibility to WiFi. The proposed method employs an innovative way to concurrently schedule a busy alarming tone and a data transmission without affecting the interference among the devices within networks. Authors have implemented and evaluated the proposed CCS on the TinyOS/MICAz and GNURadio/USRP platforms. Based on the extensive experimental evaluation results, the work has shown that proposed CCS reduces collision between ZigBee and WiFi by half (50%) for most cases, and by up to 90% when the system is concealed in a high-level interference, bearing negligible WiFi performance loss in all cases.

802.11b/g standard is widely used WiFi standard throughout the world to access Local Area Networks (LAN).

The issue of interference is worked out by Sharad et. al [68] and have introduced a simulation model which completely figures out the ZigBee and WiFi coexistence. Authors have proposed a new algorithm called *frequency agility based interference avoidance algorithm*. This proposed algorithm detects interference and dynamically switch nodes to safe channel as per pre-configuration to avoid WLAN interference with reduced latency and energy consumption. The performance of proposed algorithm in ZigBee co-existed with WiFi is empirically evaluated with respect to the packet error rate (PER) and bit error rate (BER). Based on the simulation results, the proposed work revealed that the design guidelines could efficiently determine and inform the effect of WiFi interference and thereby improve the performance of ZigBee networks.

2.6 Studies related to the improvements for application orientation

Alnuaimiet. al [69] have provided a brief description of ZigBee standard comprised of both physical (PHY) and medium access control (MAC) layer. Their work has focused on developing MatLab/Simulink models for the Zigbee protocol. Authors have also attempted to evaluate the performance of these models. Their work presented a comprehensive analysis of Zigbee performance. Simulation results show the affect of data rate and input signal power to noise channel in relation between signal bit error rate (BER) and signal to noise ratio (SNR).

The concept of ZigBee could be employed in various local sensor networks. One of the potential applications of ZigBee could be in health care industry. The system of measuring and collecting human biosignals comprised of biosignal devices for measuring a human biosignal and PDA for collecting bio signals may be customized in advanced healthcare systems. In such a system specific biosignal device has a fixed connection with the same PDA all the time. In an wireless personal area networks, several PDAs may try to send beacon messages to biosignal devices, still the exact PDA should receive the signal and remaining should ignore. Jung and Lee [70] have devised an algorithm to meet the requirements of ubiquitous healthcare system. Scanning time being the crucial parameter in their proposed work found to be improved when compared with Wireless MAC and PHY specifications for LR- WPANs.

Mohammad Alasli et. al [71] described a novel method for determining the direction of a phenomenon like wind with the help of wireless sensor networks (WSNs). The proposed method is based on a topology of sensor grid and primarily depends on analyzing the timestamp of each node in the grid at the coordinating station. Simulation experiments are carried using OmNet++ and MiXiM 2.1 framework to evaluate the topology and routing protocol. Throughput, latency and average power consumption are computed and crosschecked with other related work in order to investigate the efficiency of the proposed method.

The enhanced standard of Zigbee is standardized as 802.15.6 and termed as Wireless Body Area Network (WBAN). This newly developed standard is highly useful several applications especially for patient monitoring. Research thrust in the areas of WBAN is increasing rapidly well particularly in the field of patient monitoring when employed using WBAN communication system. The MAC protocol should be refined in such a way that it should follow stringent monitoring requirements. In this context, Bradai et. al [72] investigated in observing and enhancing the most efficient and WBAN MAC protocols. Authors illustrated the performance of the IEEE 802.15.6 standard, IEEE 802.15.4 (Zigbee MAC) and TMAC protocols subjected to different working conditions. Authors elaborated their work using different scenarios in order to simulate the MAC protocols using CASTALIA framework and OMNET++ network simulator. Finally the work also computed the end-to-end delay (E2E) for the worst case scenario using these refined MAC protocols.

Human detection is a major parameter in wireless device-free passive communication especially needed in indoor location-based services like asset monitoring, critical responses, privacy-preserving children and elderly monitoring, etc. The optimal detection of human is a complex mechanism since the feature of received signal differs with varying multipath propagation conditions and the mechanism requires on-site calibration procedure which is complicated to decide. Such a resistance could impede readily and immediate installation of wireless device-free human detection systems in practical indoor environments. Liangyi et. al [73] explored PHY layer multipath profiling information to measure a novel quantitative metric K_S as a key parameter for estmating link sensitivity, and thereby develops a linear detection threshold prediction model. Authors designed an adaptive device-free human identification mechanism that automatically determines the detection threshold based on the richness of multipath propagation within vigilance areas. Authors implemented the scheme within a traditional WiFi overlapped with ZigBee infrastructure and evaluated it in conventional office environments. After carrying thorough experimental results, the proposed scheme yields improved performance when compared with the state-of-the-art, yet requires no on-site threshold calibration.

Monitoring of Environment is an urgent requirement to the perishable food supply chain management, because of its importance in estimating the food quality and to predict its shelf life. Junyu et. al [74] have developed a system to monitor based on ZigBee-standard wireless sensor network (WSN). Certain crucial enhancements are made in the architecture of comprehensive sensors along with the network switching scheme to comply with the running applications. Authors established a tree-topology WSN system with is comprised of 192 EndNodes and a star-topology WSN system with 80 EndNodes are implemented with an intent of evaluating both functionality and performance. Data communication found to 99% with the proposed enhancements. Based on the theoretical analysis and practical measurement results, the work identified that the EndNodes have a lifetime long enough for the application of supply chain monitoring.

Numerous researchers are working for several decades to refine approximation algorithms for constructing minimum routing cost tree (MRCT) that optimally reduces the overall routing cost of all pairs in a tree topology. Normally, existing algorithms are primarily represented using graph theory which is difficult to employ them to multi-hop wireless

ad-hoc networks because of their theoretical and centralized methodology. Wireless ad-hoc network protocols follows a restriction rule which indicates the maximum number of children a parent may have. This control is to prevent bottle necks in traffic. Important finding is that limitation has not been ignored by most of the existing algorithms. Kim et. al [75] have defined the degree constrained MRCT (DC-MRCT) problem and figured out the characteristics of DC-MRCT by studying all feasible tree topologies for the given number of nodes. Depending on these properties the proposed DC-MRCT which has the minimum sum of tree level and the maximum square sum of subtree sizes could be suitable to any type of wireless network protocol if enhanced with the distributed nature. The newly proposed is termed as distributed DC-MRCT Formation (DC-MRCTF) algorithm could be applicable any ad-hoc wireless protocol working on tree topology. The proposed algorithm was evaluated in ZigBee for performance and found that DC-MRCTF is more advantageous for individual communication pair compared with the representative tree formation algorithm and is measured as much as 80%. The proposed algorithm significantly reduces the sum of routing cost of all pairs irrespective of network density.

Each wireless protocol has its own role to fulfill different demands. Heterogeneity and coexistence could be two limitations which resist devices to identify the available networks with high accuracy and low cost. Li et. al [76] have proposed a novel demodulation-free protocol identification which is economic and is of reduced complicated compared to traditional demodulation-based identification method. Extracted features from physical layer are adequate to this novel method. The proposed method initially grabs features from physical layer to locate various protocols within the network. Authors also proposed a sparse sequence based Precision-Stable Folding Algorithm (PSFA) to detect periodicity feature. Authors then constructed a prototype with USRP to identify three commonly used protocols in the standard operating 2.4 GHz ISM band. Based on the experiment results, the proposed work found that under low or moderate channel utilization, the accuracy is above 90%. The work is also concluded that the computational complexity is polynomial.

The concept of grid technology is applied to several fields like sharing of computation and power distribution etc. The potentiality of a smart grid in the modern infrastructure of the electric grid is devised with the objective to improve efficiency, reliability, and security. This could be attained through the revised control automation of the transmission and distribution lines, the update of metering technologies, the leverage of renewable energy sources, and novel energy management techniques. The rapid rise of demand of energy has a significant impact in change of global weather, issues in the storing and distribution, and thus there is an urgent need to implement more efficient metering systems to establish a robust electric grid. The concept of Smart Grid is an evolutionary metering infrastructure (AMI), which provides a duplex communication between appliances and meters at the customer side. Diego and Sandra [77] have pursued a survey and outlined main features of this AMI infrastructure which includes a classification of communication technologies and routing protocols deployed in the Neighborhood Area Network domain. Scalability, interoperability, latency, security, and quality of service are crucial parameters for any network and keeping this in mind; authors formulated a set of metrics for the AMI network using these parameters and presented a thorough analysis and comparison of AMI-related routing protocols and technologies. Certain open issues belonging to both wired and wireless technologies along with routing for the neighborhood area network domain are also presented in the work.

Naagesh [78] presented a novel method to analyze and compare power consumption of existing wireless data transfer embedded systems. Author implemented a minimal subset of the IEEE 802.15.4 protocol to obtain a point to point communication. The implemented protocol adheres to 802.15.4 MAC data and acknowledgment packets. Power consumption is measured during a single data packet transmission. Similar analysis is carried to measure the power consumption of available embedded systems and a comparison is presented. Author implemented the 802.15.4 protocol using Verilog language. Implementation is performed in such a manner so that it can be feasible to port to any platform with minimal changes. The work is also made to suit any special experimental setup requirements.

ZigBee could be best solution for the state of the art measuring infrastructures. The existing routing algorithms could not fully satisfy the requirements of the application, and thus nature of the node deployment and the flow of data is much more focused. Jiasong Mu [79] proposed a minimum physical distance (MPD) delivery protocol which is executed at ZigBee coordinator to optimize the transmission of the monitoring and command packets complaint on ZigBee specification in a smart grid environment. A neighbour table which includes transmission paths is prepared to introduce physical depth to indicate the least hops to the ZigBee coordinator. The proposed work is simulated and found significant improvement in the performance of the monitoring and controlling packet transmission. The work provided high reliability in locating optimal paths thereby end-to-end delay was also shortened.

Nisha and Yask [80] focused in presenting an overview of widely used transceiver standard i.e ZigBee technology. Authors have presented Zigbee wireless standard and its corresponding IEEE 802.15.4 specification along with the stack architecture and applications.

Sometimes ZigBee could not be considered for certain applications. Thus such a situation needs to improve or develop new wireless communication suitable for wide variety of applications. Reasons why ZigBee could not be supported for certain applications are discussed by Tomas et. al [81]. Authors developed a new wireless communication standard tailored to the industrial needs which has been termed as WirelessHART. The design features that makes WirelessHART more suitable for industrial applications and requirements is presented in the proposed work.

Qi Yong et. al [82] have pursued researched in studying the significance of attribute access methods of MAC layer in wireless communication network. Authors have aimed to conquer the issue of the shared ZigBee wireless channel which results in multi-channel device conflicts during the use

of the data channel simultaneously. The work is therefore focused to enhance the protocol and thus a method is proposed to access the properties of ZigBee. This proposed method assists to observe 29 properties MAC layer. The proposed method could help in saving storage space and expansion of functionality.

An effective identification of underground fuel concentration is one near critical application where ZigBee could be perfectly accustomed. Su Baishun et. al [83] have developed a method to develop ZigBee sensor based network installed underground to detect mine gas concentration located underground in an effective and efficient manner. The proposed methodology makes the ZigBee network to adapt to the environment of underground located coal mine, then presents the detailed design of physical structure of system, network architecture and its underlying hardware and software.

Researchers, manufacturers and designers of wireless devices always strive to locate different ways in order to reduce their cost-of-test (COT) and time-to-market for their developing products. As the functionality and complexity rise day by day it is a challenging role to measure well particular in modern applications. Parveez Javeed [84] an application engineer at SeaSolve Inc., have attempted to bring out in gathering requirements of testing wireless PAN devices at the RF and baseband level to assure their quality and interoperability. The organization SeaSolve Inc., offers a unique approach in performing such a test of checking functionality of the PHY and MAC layers of 802.15.4 devices. Once these two layers are thoroughly verified, developers have the freehand of to implement their protocols for the rest of the OSI stack.

During inception of ZigBee, an image sensor network platform is designed and developed to evaluate transmission of images in ZigBee networks which have the capability of multi-hopping. Georgiy et. al [85] implemented 802.15.4 MAC layer protocols a single M16C microprocessor to evaluate the proposed work. Fragmentation and reassembling which are the functionalities of transport layer are made to perform at the application layer because ZigBee NWK does not have a fragmentation support. CSMA/CA is channel allocation scheme available during the period and authors are progressed their work using CSMA/CA to evaluate transmission of JPEG and JPEG-2000 images. The work has presented various observations and statistics based on the results. Certain open issues are also discussed in the work.

There are certain applications of ZigBee which may be critically limited by its categorization as a low data rate standard. Ryan et. al [86] described a three-phased approach for measuring and obtaining maximal throughput over a ZigBee wireless network. These three phases are comprised of i) practical computations, ii) simulations using NS-2 and iii) implementation of hardware on Ember Corporation EM2420 based development equipment. The first two phases has given an approximate feasible upperbound of 120kbps. The final phase is focused to identify maximal throughput in an actual hardware implementation. Based on the results the work reveal maximum throughput reached 110kbps over a a ZigBee wireless network running on well-refined hardware design. The proposed work has presented the scope of future ZigBee hardware designs related to achieve maximum network throughput.

2.7 Studies related to the scheduling and resource management

Yuehuai Ma et. al [87] investigated the performance of resource management systems. Their work is a refinement of the work presented by Giovanni et. Al [19]. The main idea of Yuehuai is to focus on improving the cross-layer design for the packet scheduling and adaptive resource allocation for multiuser orthogonal frequency division multiplexing (OFDM) systems. This means authors try to develop a MAC-PHY layer scheduling mechanism to support a more practical environment in which users receive signal with different SNR level in a cell. Their proposed algorithm gives fair scheduling at MAC layer and by taking best usage of wireless resource at PHY layer. Based on the simulation results, it is found that the proposed algorithm satisfied most users in various SNR with better average performance in packet drop rate, packet delay and total throughput.

The perfect estimation of PHY layer conditions would help in doing good cross-layer resource management and provisioning. This is not happening with most of the commercial-of-the-shelf (COTS) devices because their manufacturers who provide very limited information. For example, Zigbee radios standardized on IEEE 802.15.4 provide the status of only certain attributes via.received signal strength indicator (RSSI), link quality indicator (LQI) and noise floor readings. These readings are stored in frame check sequence (FCS) of MAC frames. Guanbo et. al [88] have revisited this issue of link quality prediction in IEEE 802.15.4 standard. They have analyzed and experimented low rate wireless personal area networks (LR-WPAN) of IEEE 802.15.4 standard. Authors for the first time have deciphered LQI readings available in Zigbee radios with CC2420 chipset and found that the LQI actually gives the signal-to-noise ratio (SNR) at receiver. Using measurement studies, they also investigated the chip correlation (CORR) defined in CC2420 data sheet, and verifed its relationship with LQI readings. An inference model is developed to predict the instantaneous link quality for commodity Zigbee radios. This model runs under different channel environments that use instantaneous LQI readings as input. The proposed model is tested using extensive simulation and experimental study. Authors strongly opined that the proposed work could lead to more informed resource management decisions in WPANs.

The amplify-and-forward (AF) scheme multiple-hop MIMO relays system is proposed by Hiep and Kohno [89] for the high end-to-end channel capacity. In order to prevent certain relays from being the bottleneck and assure the high end-to-end channel capacity, the distance between each transceiver and the transmit power of each relay node are made optimized. The performance of the system gets deteriorated when the system has no control on Mac layer because of the interference signal. It is needed to analyze specific control transmission for each relay. The channel which uses high capacity could be obtained with the help of access control. This results in increase of delay time. The proposed decode-and-forward scheme is analyzed and results are compared with AF scheme for its improvement.

Wide applicability is one the major benefit of IEEE standard 802.15.4 for its continuous study. Mohammad et. al

[90] presented a study based upon analyzing techniques and methodology discussed in IEEE 802.15.4 standard. The work is pursued within the context of contention access period. Based on the standard specifications, two minor variations are observed in CSMA/CA algorithm which is employed in CAP along variable frequency ranges. Globally these frequency ranges are fully accepted. One flavor of MAC supports ACK frame after successful transmission while others do not support. The behavior of ACK mode of CSMA/CA is thoroughly analyzed and simulated by several researchers. Still no studies exist giving the discussion on behavior of non-ACK mode. This non-ACK mode is considered as another flavor of MAC in IEEE 802.15.4 suitable for applications that do not concentrate on taking ACK packet after every transmission. Authors modified a markov chain model for non-ACK mode and compare both modes of ACK in an analytical manner using extensive simulations and discussions. The work is proved worth particularly, for health care applications when employed with ACK. Non ACK too gives best results in streaming data or playing games because of its lower delay, higher throughput and lower control load.

Several articles have been reported in the literature toward devising a novel efficient Medium Access Control (MAC) protocol to overcome the limitations of the IEEE 802.15.4 standard MAC. Guennoun et. al [91] pursued experimentation in devising efficient IEEE 802.15.4 MAC and focused on exploiting the Clear Channel Assessment (CCA) feature in a better way. Authors proposed an improved Variable CCA MAC protocol which increases the number of CCAs performed by a network node beyond the benchmark standard value. Authors developed a Markov-based mathematical model describing the functionality of the proposed revised protocol. The devised mathematical model is further evaluated through extensive simulations to identify the impact of certain significant parameters like collision probability, throughput, channel idle time, channel collision time, energy consumption, delay, and reliability respectively.

Rapid increase of productivity, low cost and consumption of low power gave rise to a rapid use of IEEE 802.15.4/ZigBee Wireless sensor networks. These devices are capable of serving variety of applications like gathering critical, real-time information for remote surveillance, environmental monitoring, and distributed target tracking etc. The only IEEE standard ZigBee provides network security, and application support services working following the standards of the IEEE 802.15.4 Medium Access Control (MAC) and Physical (PHY) Layer wireless protocols. MAC unreliability problem found to be one major limitation in the IEEE 802.15.4/ZigBee sensor networks. Literature studies identified that the unreliability problem is because of MAC parameter configuration defined in the original standard. Several solutions for this issue are addressed like setting a predefined value for parameters which best suits for static conditions, design of mathematical models that can adapt for dynamic conditions etc. Sangeetha and Suriyakala [92] have presented the analysis of ADAPT algorithm and its impact during packet delivery within a ZigBee network. These authors have carried experimentation with and without ADAPT and simulations are obtained from NS2. As a process of security measure authors have considered the signature verification for each node in the sensor network.

The promising technology of cooperative communications is widely enhanced over traditional access and transmission schemes especially in wireless networks. The participating nodes which cooperate during transmission are the key units which give the performance of the network. Additional collaboration of these nodes preserves spatial diversity and thus improves the performance of the network. Feilu Liu [93] has proposed a cross-layer protocol which is based on a MAC protocol called CoopMAC. This protocol is designed for ad-hoc wireless networks to make beneficial cooperation in both MAC and PHY layers. This proposed scheme has illustrated a new paradigm works efficiently by exploiting physical layer at receiver. The scheme is targeted to perform realistic cross-layer cooperation for next generation wireless ad-hoc networks. Authors have evaluated the performance of the proposed protocol with the help numerous simulations in a large scale wireless ad-hoc network. Based on the simulation results authors found that the proposed scheme has significantly improved the network performance in terms of throughput and delay.

For ZigBee, a group of companies formed as SIG and worked to develop specifications for stack profiles, which include the definition of network, application services and security parameters for the entire network. ZigBee coordinator takes the responsibility of selecting stack profile and this selection is based on the ZigBee running applications like home control, building automation or plant control. Zucatto et. al [94] have described some important aspects of ZigBee and IEEE 802.15.4 along with the main directives of the stack profile and network topology. The selection and assembling of first development kits are also presented in the work.

Junjie Chen et. al [95] have analyzed the packet error rate (PER) of Zigbee (IEEE 802.15.4) to develop a mathematical model of the mutual interference. Their analysis is carried under the interference of radio frequency identification (RFID). Their proposed model takes PHY and MAC into consideration. PHY layer is to observe the channel model, the transmitted power, the frequency spreading and the frequency modulation. MAC is considered for analyzing traffic load and the packet format. The parameter packet error ratio (PER) is derived from the bit error rate (BER) and the collision time. The proposed methodology is evaluated with adequate simulations.

III. SUMMARY

Numerous researchers have attempted in improving ZigBee MAC and PHY compatible with respect to several industrial applications. John O Sullivan is the actual developer of ZigBee created a new boom in the data communications. Vic Hayes has been recognized as the key contributor from IEEE who standardized the ZigBee communication and made it available to the common man. Most of the literature reported works focused on several issues of ZigBee and tried to improve the functionality and performance of ZigBee. Still, the efforts of doing enhancements of MAC and PHY in ZigBee towards low power consumption is little worked and thus has a great scope of the proposed study.

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