QoS Aware MAC Protocol for Wireless Video Sensor Network

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QoS Aware MAC Protocol for Wireless Video Sensor Network

Major Project

Submitted in partial fulfillment of the requirements

for the degree of

Master of Technology in Computer Science and Engineering (Networking Technologies)

Submitted By

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Guided By

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Certificate

This is to certify that the major project entitled **"QoS Aware MAC Protocol for Wireless Video Sensor Network"** submitted by **Vrajni Shah (Roll No: 14MCEN21)**, towards the partial fulfillment of the requirements for the award of degree of Master of Technology in Computer Science and Engineering (Networking Technologies) of Nirma University, Ahmedabad, is the record of work carried out by her under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project part-II, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Statement of Originality

I, **Vrajni Shah**, Roll. No. **14MCEN21**, give undertaking that the Major Project entitled " **QoS Aware MAC Protocol for Wireless Video Sensor Network**" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Computer Science & Engineering (Networking Technologies)** of Institute of Technology, Nirma University, Ahmedabad, contains no material that has been awarded for any degree or diploma in any university or school in any territory to the best of my knowledge. It is the original work carried out by me and I give assurance that no attempt of plagiarism has been made.It contains no material that is previously published or written, except where reference has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Abstract

Today the wireless sensor network provide services to many applications from home and industry automation to border surveillance. The technology becomes popular because required hardware is easily available at low cost. Recently the wireless multimedia network has captured researchers attention. The cameras for multimedia application are easily available at low cost. Multimedia network is capable of capturing video and audio along with scalar data. This mission critical application requires the certain level of QoS. The IEEE 802.15.4 standard provides PHY and MAC layer services to these low rate wireless personal area network application. This standard suffers from MAC unreliability problem even if network size is small. The IEEE task group gave their efforts to improve MAC performance of IEEE 802.15.4 standard. IEEE 802.15.4e standard is MAC enhancement of it. In order to reduce radio duty cycle, a novel approach is proposed. The approach helps to achieve energy efficiency. The results show that node startup time consumes the significant amount of energy. By fixing EB channels and skipping slots or entire slot frame the average consumed node power reduces compared to TSCH protocol of IEEE 802.15.4e.

Abbreviations

ACK	Acknowledgement.
BI	Beacon Interval.
BO	Beacon Order.
CAP	Contention Access Period.
CCA	Clear Channel Assessment.
CFP	Contention-Free Period.
CSMA	Carrier Sense Multiple Access.
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance.
CW	Contention Window.
EB	Enhanced Beacon.
EBR	Enhanced Beacon Request.
FFD	Full Function Device.
GTS	Guaranteed Time Slots.
IEEE	Institute of Electrical and Electronics Engineers.
MAC	Medium Access Control.
NB	Number of Backoff.
PAN	Personal Area Network.
PHY	Physical Layer.
QoS	Quality Of Service.
RFD	Reduced Function Device.
RPL	Routing Protocol for Low-Power and Lossy Networks
SD	Superframe Duration.
SO	Superframe Order.
TSCH	Time Slotted Channel Hopping.
WSN	Wireless Sensor Network.
WMSN	Wireless Multimedia Sensor Network.
6LoWPAN	IPv6 over Low power Wireless Personal Area Networks.

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Contents

List of Figures

Chapter 1

Introduction

1.1 Introduction to WSN

The developing interest towards Wireless Sensor Network (WSN) creates many research opportunities for industry researchers. These sensor networks carry sensor nodes capable of identifying environmental and physical changes. Low cost of these basic hardware attracts vast domain of consumers. Nodes are having one processing unit, sensing unit, computation and communication unit, transceiver, antenna, microcontroller [3]. In this project, Zolertia Z1 sensor node is used for simulation which includes the CC2420 transceiver. The sensing unit keeps watching on temperature or another phenomenon for which the application is intended for. As soon as it notices some changes in environmental conditions it notifies to a processing unit. Processing unit gathers data and computes some results with the help of computation unit. This whole network is equipped with very limited battery power at each node. The wireless channel provides the medium that transfers captured data to sink node or to the network. Sensor nodes are deployed in very large amount mostly in the random fashion or in some cases very specific pattern. They are once deployed then subjected to organize by themselves, that is self-organizing in nature.

1.1.1 Characteristics of WSN

1. Node mobility:

   Network links are formed dynamically, that is nodes can join to the network whenever they wish and disjoin network when they are out of the range.

2. Unattended operation:

   That is self-organizing nature of member nodes without any intervention from human

3. Dynamic Network Topology:

   Re-deployment of the network is required due to node failure, failure of radio links or disturbance of some mobile obstacles [4].

4. Limited power:

   Sensor networks are deployed in such places where energy recharge or replacement is not an easy task for larger nodes. So energy consumption is the main phenomenon to increase the lifetime of the network. Energy saving can be done at three stages node communication, sensing and computing the results.

5. Large scale of deployment at larger scale:

   The huge amount of sensor nodes and physical conditions like noise, interface and available bandwidth influences the quality of channel and link connection between nodes.

1.2 Introduction to WMSN

The current applications of the wireless sensor network are mainly based on scalar data like temperature, pressure, humidity, light and location of object [5]. This application requires very small amount of data to capture, compute and transfer. Applications are less stressed about a strict timely delivery of data. But recently developed cheap and affordable hardware like CMOS cameras direct the industry to the multimedia sensor network. The network that can sense scalar data along with audio and video.

1.3 Motivational Applications

Target applications can be home and industry automation, surveillance, border surveillance, traffic management, product management, healthcare, agriculture, at the civil site for example at the bridge and much more are possible [6]. All applications require higher reliability and less delay tolerant. Moreover, the multimedia data has heavier content than scalar data that requires the larger amount of data to be transferred within no time.

Multimedia sensors will not only serve new application but can modify existing sensor network applications up to certain level.

1. Multimedia surveillance system

   Wireless video sensor networks are made up of interconnected video sensors having processing, power, and the transceiver unit. Video and audio sensors can assist police and other governing committees to a very large extent. Sensors cover very large area and can help for patrolling, as an evidence in the case of terrorist attack or other mischiefs. It can also be helpful at public events and at borders. Person locator service gives information of terrorist with the help of video streams.

2. Traffic control and monitoring

   This newly invented sensor network technology can be helpful for traffic control and better routing in vast and metro cities where traffic jam is a big issue. It identifies congestion and quick action can be taken from remote areas.

   Smart parking and machine operated parking services can be developed in congested areas for better utilization of parking space. Moreover, on highways calculation of cars, busy hours, type of cars can be easily analyzed.

3. Health assistant

   Patients can carry medical sensors with audio and video capturing capabilities. They can measure health parameters like the heartbeat, ECG etc. Doctors can remotely keep watch on the health condition of patients with these multimedia sensors.

4. Robotics

   Multimedia sensors can improve the performance of robotic machines . In large manufacturing unit it can keep watch on any unwanted behaviour.

Such multimedia sensor network requires Quality of Service (QoS) [7] at the certain level . It is very difficult to obtain good QoS in such unreliable wireless network and resource constrained nodes. Traditional multimedia surveillance network require higher bandwidth , where nodes are more battery powered and it covers the smaller area than wireless multimedia infrastructure. So new techniques and protocols should be developed and many types of research are going on for these resource constrained and unreliable network. Specifically, for video sensor, it requires high throughput, low data delay, minimum jitter, high reliability and best effort delivery with the best energy saving mechanism.

Surveillance application requires very critical information to be sensed or captured. So any compromise in audio and video quality is not tolerated. The quality of captured data should be enough to identify person or event very clearly. Additionally, video sensor network faces some issues like improve network life with limited battery power, the efficient compression algorithm that requires very less computation at sensor node and is less complex. Packet loss is one of the major criteria to be taken care of for video transmission.

The layered architecture of win includes physical, MAC, Network, Transport and application layer. PHY and MAC layer are managed by IEEE 802.15.4 standard. Network layer protocols are generally IPv6 or RPL , which is routing protocol for lossy networks and low power. Application layer includes Zigbee, 6LoWPAN, and other IoT-specific applications.

This article discusses MAC layer. The reason behind optimizing the MAC layer is that it is the primary influential factor for the overall performance of a whole application and network behavior.

The IEEE 802.15.4 protocol is newly adopted communication standard for wireless personal area network with low data rate, low power, and low cost. The protocol is suited for multimedia sensor because of the provision of guaranteed time slots for time critical and reliable data transmission. Many other standards like ZigBee, 6LoWPAN are based on MAC features of IEEE 802.15.4. Due to some limitations of this standard new standard IEEE 802.15.4e is developed. It is the MAC enhancement of previous protocol. PHY layer is kept as it is on this standard. It suggests slot frame structure rather than superframe structure.

In general, this article is based on most adopted MAC protocols of wireless sensor network suited for multimedia sensors. Providing QoS to existing technology. Modeling and simulations are performed on Contiki environment.

Chapter 2

QoS in WSN

2.1 Overview of QoS

To fulfill the multimedia requirements to wireless sensor network WMSN is developed. It is applicable to newly invented applications from surveillance to automation. It just not give a boost up new applications but improves the performance of existing multimedia applications. It improves existing applications by adding cameras and microphones to a scalar sensor used in traditional WSN. So WMSN carries heterogeneous traffic requiring different QoS by each type of captured information. So it is very basic need for deployed network to provide QoS to this heterogenous environment with different requirements. Traffic like video, audio and scalar data makes captured data heterogeneous. The main QoS hungry applications are real-time multimedia and mission-critical applications, for that timely delivery, reliability, and less packet loss is important. With the help of resource sharing technique, QoS gives different priorities to different users, frames or packets, applications or data flows, hence, can serve service differentiation among categories to their requirements respectively. Since MAC layer plays the most important role for medium sharing and all upper layer protocols are dependent to that, it has the capability to improve the long-term performance of the WMSN. Therefore choosing MAC layer to provide QoS is very wise thought.

2.1.1 Unusability of Traditional QoS MAC Protocols

Traditional multimedia applications need end-to-end strict bandwidth so a reservation-based approach that is Integrated services can be used. It provides reservation on the per-flow basis. Wireless links are very hard to predict so for that QoS provision is very challenging work. Furthermore changing network topology and limited resources makes it very uncomfortable to use traditional MAC schemes. In order to fulfill needs of mission critical and delay sensitive real time applications designing new QoS protocol stack in each layer is the better option. QoS can be provided centrally or in distributed manner. The main reason not to use central approach in WMSN is large amount of sensor nodes, multi-hop communication and varying network size.

2.1.2 Factors Affecting the QoS

Multimedia application requires high availability of service, low delays, reliability, and stability of service. These requirements can be mapped to technical terms like applications basically needs lower packet latency and higher throughput. If these user requirements are not fulfilled properly User experience can be degraded and application turns to useless. As packets travel from sender to receiver in such unpredictable wireless link several problems can take placket that affects packet delivery and ultimately decrease the QoS level.

1. Errors :

   In wireless communication, the reason behind packet corruption is noise and interference. At the receiver end, packets are detected if it is corrupted or not and if yes then recovery mechanisms are applied for a meaningful reception. If it is impossible to recover packet is dropped.

2. Low throughput:

   When there are many users parallelly sharing the same resources the maximum achievable throughput for that stream can be very low. It happens particularly for applications consuming higher bandwidth such as audio or video streaming. When the intermediate node receives data beyond its capacity results in network congestion. The problem arises because of buffer overflow, it discards all packets after overflow condition.

3. Packet loss:

   Packet loss degrades the quality of application loss-sensitive applications like e-mail must provide reliable end-to-end delivery of data.

4. Delays:

   Packets delay is measured as time taken from packet transmission to packet reception at the receiver. The main reason of delayed packets are propagation, queuing and processing delays. As network load increases queuing delay increase simultaneously. Some application are delay tolerant and some are not but timely delivery should be assured. If the packet delay is very large then it becomes outdated and so dropped.

5. Jitter:

   Jitter can be defined as a variation in packet delay. Real-time applications are more concerned about that. The problem can be solved by another buffer at receiver end it removes jitter effect at the cost of increased delay at that buffer.

6. Out-of-order delivery:

   When packet delays variation losses their sequential order in which they were sent some reordering mechanism is needed. It causes the additional delay of queuing and processing. Video and VoIP applications are majorly affected by latency, jitter, and out-of-order packets.

2.2 QoS Provisioning at the MAC Layer

As stated earlier MAC layer plays a key role to provide QoS in the wireless network. The radio channel is shared and nodes can not access it simultaneously so the overall performance depends on how optimally resources are managed [8].

2.2.1 Design-drivers for WSN MAC Protocols

An efficient MAC protocol can be achieved by providing fair channel access to participating nodes along with minimum collisions, maximum throughput and more importantly energy saving. Before developing a good QoS-aware MAC one should understand the main causes of energy and bandwidth waste.

Collisions

Collision plays the major role in network performance, MAC scheme should reduce collisions as many as possible. Collision wastes all energy invested in packet transmission and at receiver collided frames are just all waste [9]. The IEEE 802.15.11 uses RTS-CTS mechanism to cop-up with a collision. But this technique is not suitable for wireless sensor network due to highly resource constrained environment. RTS-CTS consumes more energy as it creates the extra burden of transmission of these packets. In some cases, the data packet is smaller than the collision avoidance packets. One of the energies efficient approach is receiver initiated the collision avoidance scheme. The basic idea is that data exchange is receiver initiated, receiver invites senders to transmit data. This can be achieved through periodically advertising polling message to intended sender. The receiver allows the new user in that advertisement and informs new users the current channel condition and allocated slots or links that are contention free in order to avoid collisions. By this scheme receivers can save energy by turning off their radio and avoid idle listening. For the connected nodes, no further synchronization is needed when receiver wake up to trigger the pending data transmissions.

Overhearing and idle listening

As energy efficiency pays the major role in network lifetime, a network should keep functioning as long as required by the application. In most sensor network the radio is the most energy consuming module. Radio duty cycle can be optimized at MAC layer , so MAC is main layer which can work on energy saving. There are two main conditions where energy is drained. First in listening transmission that is not intended for that node, that is node listening packets intended for another node or may be a case of the redundant broadcast also called as overhearing. Secondly in the case of idle listening where nodes keep their radio on and waiting for potential incoming packets by listening to the channel continuously. The design of energy-efficient MAC protocol should be such that it keeps the node in a sleep state during long periods of inactivity.

Chapter 3

IEEE 802.15.4

3.1 IEEE 802.15.4 and ZigBee

To support automation and remote control application ZigBee standard is developed. It works on the application requiring low data rate at low cost with energy efficiency [10]. The IEEE 802.15.4 committee contributed their efforts for low data rate standard. Now ZigBee Alliance and IEEE combined their efforts and commercial name for this mechanism is named as ZigBee. This standard expected to serve connectivity at low cost and at low power. This connectivity is between motes and are expected to serve for several years or month with low data transfer rate. The transmission range of ZigBee-enabled wireless devices is normally 10-75 meters depending on the power output consumption and RF environment required for a given application. It operates in unlicensed RF 2.4GHz. IEEE and ZigBee Alliance jointly specifies the entire protocol stack. Lower layers are specified by IEEE 802.15.4 that includes physical and data link layer of the standard protocol stack. Upper layers are specified by ZigBee from network to application along with security services [11]. This standard serves application at very wide range from wireless home, industry and building control to border surveillance. Interoperability of protocols helps consumers to choose from a various range of manufacturers without botheration of interoperability problem.

3.2 IEEE 802.15.4 WPAN

The personal area standard provides network flexibility with low data transmission rate at low cost with lower power requirements. The network is capable of self-organizing devices that are cheap either fixed or moving in the network. It is intended for applications that are not strict at throughput achievement and can not sustain power consumption of heavy protocol stack.

3.2.1 Components of IEEE 802.15.4

The most basic component of IEEE 802.15.4 is a network device. It includes two types of devices , a full-function device (FFD) or reduced-function device (RFD). A network contains at least one FFD that performs a role as a personal area network (PAN) coordinator. Three operation modes of FFD are a personal area network (PAN) coordinator, a coordinator or a device. An RFD has lower capabilities than FFD and is intended for very simple applications that operate at a very basic level and send a smaller amount of data.Communication between FFD and FFD or RFD is possible but RFD to FFD is the only possible way to communicate.

3.2.2 Network Topology

3.2.2.1 Star Topology

In star topology, there is one central coordinator device and other member devices are synchronized and connected to it. The coordinator is called as PAN coordinator and it is equipped with more power than devices that are battery powered. Home automation and other such applications adopt star topology. An FFD is capable of becoming PAN as it activated and establish its own network. A particular star network is identified by PAN identifier which is unique and this identification number is not used by any other network within the radio influence area . By this mechanism, each star network can function independently.

3.2.2.2 Peer-to-peer Topology

Peer-to-peer topology also contains one central authority that is PAN coordinator. It is designed for network initialization, formation, and, synchronization. In this topology, any, device can communicate with another device in its radio range. This network can be ad-hoc having capabilities like self-organizing and self-healing [12]. The topology can be applied to applications like industrial control and monitoring, wireless sensor networks, object tracking. Any device can send a message to any other device through muli-hop

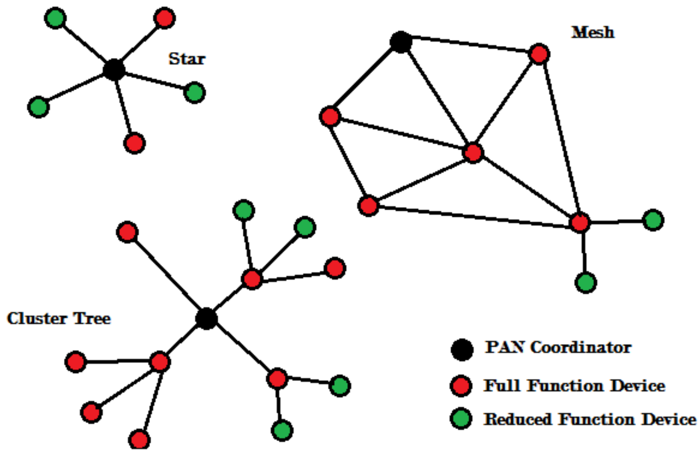

Figure 3.1: Topology models

method. It provides reliability by multipath routing.

3.2.2.3 Cluster-tree Topology

Cluster tree topology is a modification of peer-to-peer network, where majority of the devices are FFD. RFD are leaf nodes at branches of tree connected to an FFD. In this topology also there is only one FFD performs as a PAN coordinator. After activation an FFD set-up itself and generate beacons to construct a cluster. It chooses one cluster ID that is unique in radio sphere of cluster tree network. It is also called as the cluster head. Other FFD can also contribute to network discovery and can generate beacons to inform availability of network and to provide synchronization services with other member devices. New device wants to join the network , after receiving a beacon frame can request to join at cluster head. If the PAN allows joining that candidate device, cluster head adds it to its neighbor list as its child. Newly joined device adds cluster head as a parent in its neighbor device entry. Now it will start announcing beacons in order to join another device. After basic requirements of a network is completed and well formed, new PAN coordinator is chosen for ease of access the extended tree is treated as the separate cluster.

3.2.3 Device Architecture of LR-WPAN

The PHY layer contains the radio frequency (RF) transceiver. IEEE 802.15.4 define PHY and MAC sublayers. ZigBee uses MAC and PHY layer and provides application layer with or without security. For Low rate application RPL routing protocol is defined. 6LoWPAN defines Ipv6 connectivity over Low power Wireless Personal Area Networks.

The PHY layer includes radio frequency transceiver. All types of transfer over a physical channel is accessible through MAC sublayer.

Network configuration, manipulation, and, message routing is enabled by network layer. 6LoWPAN and ZigBee define applications supported by this standard.

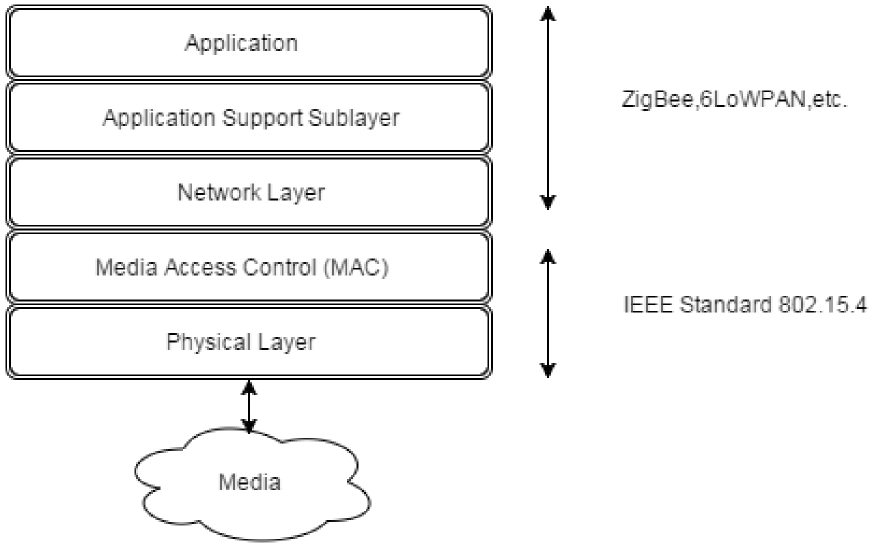

Figure 3.2: LR-WPAN device archicture

3.3 MAC Layer of IEEE 802.15.4

The MAC data service provides the data exchange of MAC protocol data unit (MPDU). Beacon management, GTS provision, channel access, frame validation, ACK frame delivery, channel access are features of MAC sublayer.

There are two channel access methods provided by this standard. First is beacon enabled a mode where power management mechanism is provided based on duty cycle. Second is non-beacon enabled mode. Power management is achieved by superframe structure bounded by network beacons. Beacons are synchronization frames periodically generated by a coordinator.

3.3.1 Superframe Structure [1]

LR-WPAN supports superframe structure. The coordinator defines the structure of superframe. It is divided into 16 equal slots and starts and ends by network beacons [13]. At first slot of a superframe, a beacon is sent by coordinator if a mode is a beacon enable. In a non-beacon mode, the coordinator turns off the beacon transmission. The superframe structure and PAN are identified by beacons. It is also used for synchronization between PAN and other network devices.

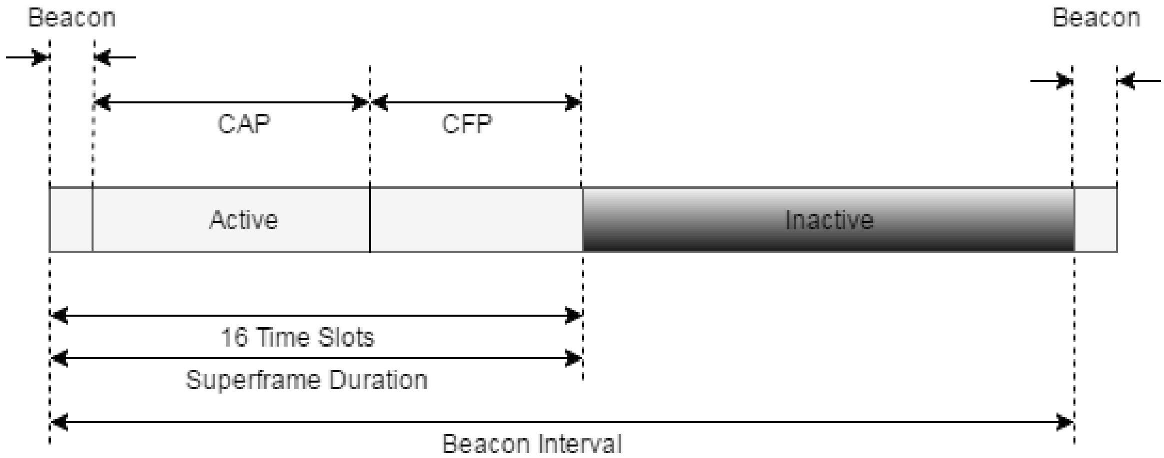

Figure 3.3: Superframe structure of IEEE 802.15.4

The superframe contains two parts active part and inactive part. During inactivity, coordinator goes to lower power mode and does not interact with PAN coordinator. The active portion includes contention access period (CAP) and contention free period (CFP). Devices have to contend with each other to get channel access in contention access period. The contention is done via slotted CSMA/CA mechanism. The contention free period consists guaranteed time slots (GTS). GTS starts with the end the of CAP and ends on the active portion of a superframe. A PAN coordinator can allocate up to seven GTS and one or more slot period can be occupied by one GTS. The duration of CAP and CFD of the superframe are defined by two values, macBeaconOrder, and, macSuperFrameOrder.

The time interval between two beacons generated by the coordinator, it is adjusted by macBeaconOrder. Beacon interval is a related term for macBeaconOrder that is BO.

$$BI = aBaseSuperFrameDuration2^{BO}, 0 \leq BO \leq 14. \tag{3.1}$$

$$SD = aBaseSuperFrameDuration2^{SO}, 0 \leq SO \leq 14. \tag{3.2}$$

If LR_WPAN does not want to adopt superframe structure the value of BO is set to 15 that is superframe is ignored. macSuperframeOrder adjusts the length of the active portion of the superframe. The superframe duration, SD, is linked with macSuperFrame-Order, SO.

If SO = 15, non-beacon mode is enabled. At slot zero for beacon transmission, CSMA is not used. A transmission in the CAP complete before some CAP ends, that is one IFS period. The CFP starts immediately at the end of CAP and ends at active portion of a superframe. The total length of all GTS describes the length of CFP. The same rule is applied in CFP that is transmission should be completed of that GTS slot before some time that equal to IFS period. The reason behind IFS period is to process received packet by PHY. The length of IFS depends on the size of transmitted frame.

Non-beacon Mode

If coordinator does not wish to use superframe structure, macBeaconOrder and macSuperframeOrder are set to 15. Devices contend for accessing the channel with unslotted CSMA/CA , ACK does not require to use CSMA mechanism. There is no GTS allocation permitted for this mode.

3.3.2 Data Transfer Model

WPN supports three types of data transfer. That is from a coordinator to a device, between to peer devices and from a device to a coordinator. In non-beacon mode device simply transmits data to coordinator using unslotted CSMA/CA. There is a provision of an optional acknowledgment by a coordinator.

1. Device to coordinator

   On the other hand, beacon-enable mode requires device first to listen to beacon transmitted by a coordinator and synchronize to superframe structure. The device can transmit data using slotted CSMA/CA at contention access or at GTS. There is an optional mechanism of acknowledgment.

   In non-beacon mode device directly transmits data without waiting for beacon and synchronization.

2. Coordinator to device

   When a coordinator requires data from a device the request indication is sent via beacon. After receiving next beacon the device notices that data is pending. It transmits data using slotted CSMA.

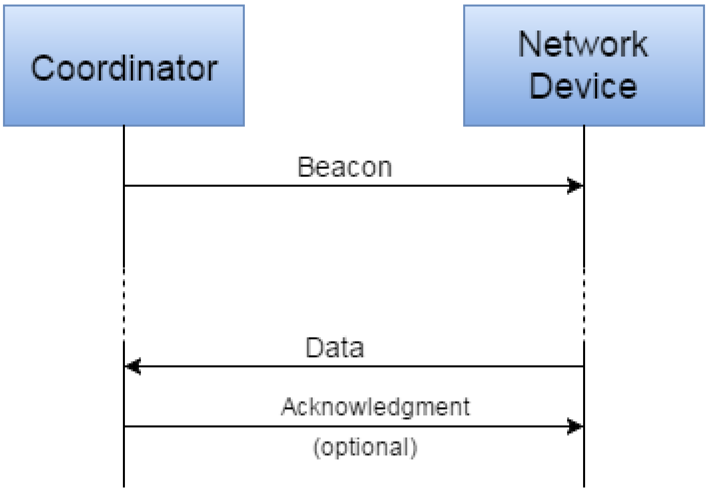

Figure 3.4: Communication from network device to a coordinator in a beacon-enabled network.

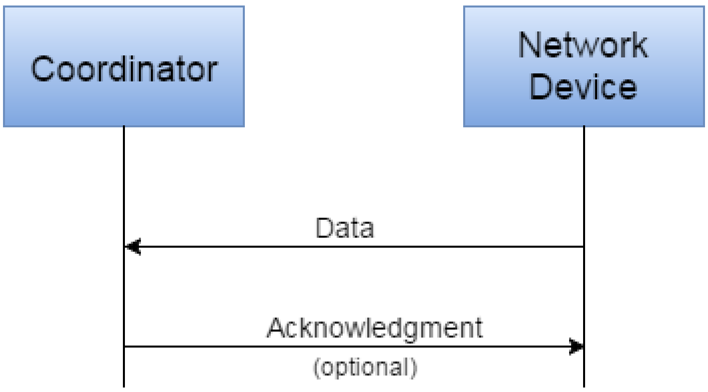

Figure 3.5: Communication from network device to a coordinator in a nonbeacon-enabled network

3. peer-to-peer network

   Every device communicates with every other device. In non-beacon mode nodes constantly listens to the channel and transmits using unslotted CSMA/CA. In the beacon enabled mode nodes synchronize with each other ultimately saves the energy.

3.3.3 Synchronization

In beacon enabled mode the synchronization is achieved by receiving and decoding beacon frames. A device that wants to acquire beacon keep watch on it by regularly and actively keeping its receiver on. It just keeps it receiver on before the next expected beacon, it keeps the record of the transmission of next superframe structure. If beacons are missed by a device the counter is incremented. Once the number of missed beacons reached the MLME notifies synchronization loss.

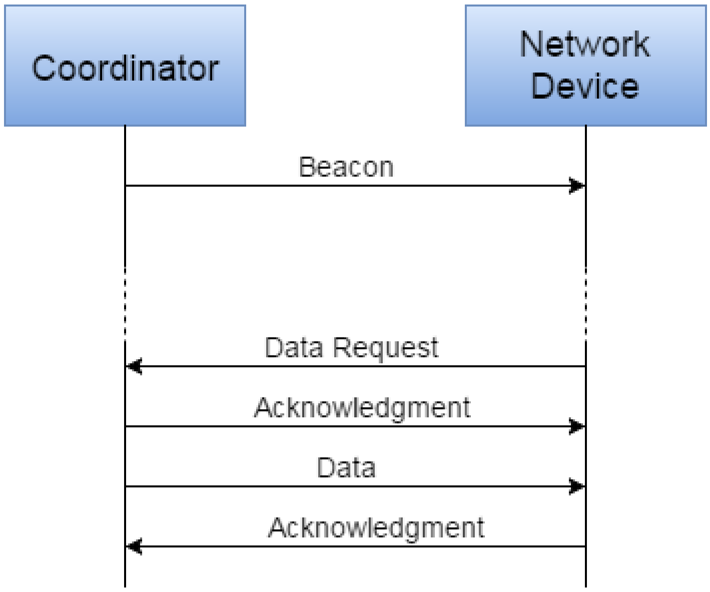

Figure 3.6: Communication to a network device from coordinator in beacon enabled network

3.3.4 GTS Allocation and Management

A GTS allocates a portion of the superframe to that service that it can operate on the channel without the interference of other devices. This service is allowed only in beacon-enable mode. GTS allocation can only be done via PAN coordinator for communication between PAN and device. A single GTS can register one or more superframe slots. Maximum of seven GTS can be allocated to a superframe. GTS are allocated prior to their use keeping in mind GTS requests received and capacity of slots. GTS allocation is performed on a first come first basis. GTS deallocation is performed by requested device when it is no longer in use. PAN coordinator can also deallocate GTS. There is a provision in which GTS allocated device can also contend at CAP. PAN coordinator stores information of all GTS like its starting slot, length, direction and associated device address. Each device request GTS with a direction that is transmitted and or received. If it is allocated receive GTS it keeps the receiver on for entire GTS slot. PAN enables its receiver on for whole GTS when it allocates transmit GTS for a device.

3.3.5 CSMA/CA Algorithm

The CSMA/CA algorithm is used in both channel access modes. In beacon-enabled mode, it is used in CAP portion of the active period. In non-beacon enabled mode slotted CSMA is not used as in beacon-enabled mode. The following steps are of slotted

CSMA/CA while data frame to be transmitted.

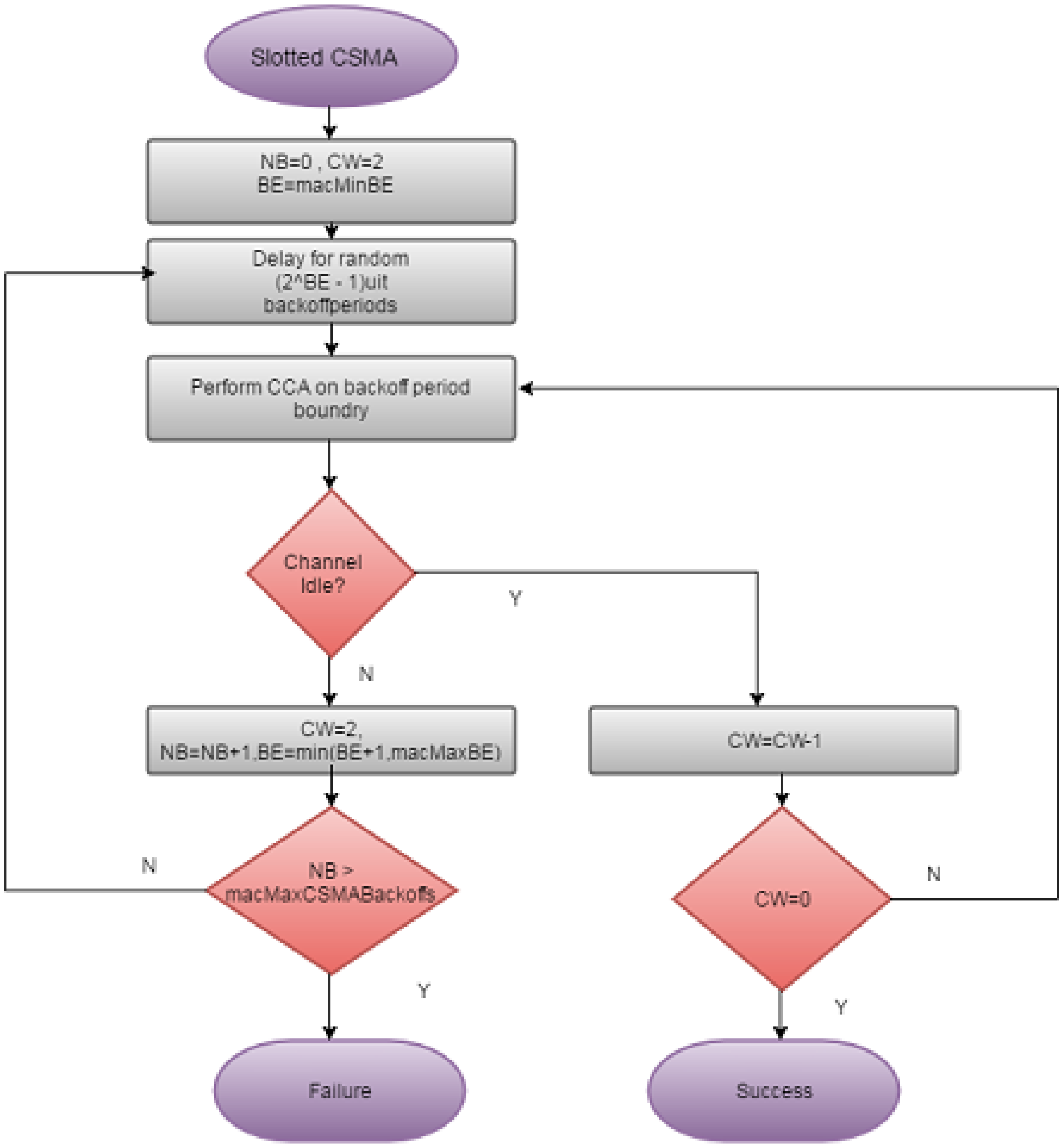

Figure 3.7: Slotted CSMA used in IEEE 802.15.4

The optional retransmission scheme is supported in CSMA/CA algorithm. When retransmission is enabled , acknowledgment is sent just after data frame received. If a sender does not receive the acknowledgement, it starts retransmission uptil the maximum allowed retransmission reached (macMAxFrameRetries). In this situation data frame is dropped.

3.4 Shortcomings of IEEE 802.15.4

- One of the major limitaions is IEEE 802.15.4 heavily suffers from MAC unreliability problem. This problem is due to power management , it is for improving the energy efficiency. It can not handle contentions even in small size network. As we increase nodes in network packet delivery ratio decrease very rapidly.

- Scalability is another issue, where a network may add some nodes or some nodes are removed due to battery constrain or may be inactive. It is not adaptable to the size of a network.

- Channel quality variation is not adapted by 802.15.4. It does not support multiple application and not much suitable for heterogeneous devices.There is no guarantee for critical transmissions.

- One of the major problems is Idle listening.Nodes continuously listen to the channel because they do not know when the information is coming.so it must keep his radio in receive mode.

- In WPAN nodes are intended for single common task so a node can have more data to send to other nodes. All nodes are treated in same way. In order to have maximum optimization from the network, fairness should be adopted which fairly distributes the channel among participating nodes.

- It does not supports mesh network and can not handle mobility in the network.

- IEEE 802.15.4 is not much suitable for real-time applications.

Chapter 4

Performance Evaluation of IEEE 802.15.4

The MAC layer performance of IEEE 802.15.4 is evaluated in this chapter. The first section introduces Contiki os. It provides a programming environment for sensor nodes. Next section introduces a JAVA based simulator, Cooja. Cooja provides a well-managed simulation environment for wireless sensor nodes. Performance evaluation section contains analytical results of MAC layer parameters on various condition.

4.1 Contiki, A Sensornet Operating System [2]

Contiki is an operating system used for sensor networks programming. Contiki is an operating system intended for power constrained microcontrollers. It is an open source os with high portability, multitasking capabilities. It consists of 2 kilobytes of RAM and ROM is of 40 kilobytes.

Primary components are a kernel, the program loader, libraries and a set of processes. Networked embedded systems and smart objects use Contiki. To program applications for the smart object or multimedia object, Contiki provides all supporting mechanisms needed. The os is programmed in C language so it is easy to develop an application in C using Contiki. The os provides different modules for different layers. The MAC module is provided in separate directory Contiki/core/net/mac. It provides IPv4, IPv6 and rime protocol stack. Rime is lightweight networking protocol that targets low-power wireless networks.

Protothreads are basic programming model of Contiki to run memory constrained systems. It efficiently uses memory sharing features of both multithreading and event-driven programming.

4.2 Cooja Simulator

Cooja is a JAVA based simulator. The sensor network running on Contiki sensor network operating system can be simulated on Cooja. It supports sensor software written in C language in spite JAVA based simulator. Contiki programs can run either on host CPU natively or compiled for MSP430 emulator. It provides nice GUI to interact with simulated nodes. It includes various tools and plugins including Simulation Visualizer, Radio logger, Timeline etc. User can save simulations in an XML file with .csc extension. CSC stands for cooja simulation configuration. The details provided by this file are network setup, node position, radio medium, random seed etc. From "project-config.h" file MAC parameters can be changed at one place for specific application.

4.3 Simulation and Network Setup

When we simulate sensor network, the simulation of losses due to wireless medium is very important to get actual results. It gives nearly perfect results where the sensor nodes will actually work. Results are as accurate as an accuracy of simulation of RF medium. The upcoming section describes the simulation of radio medium in Cooja.

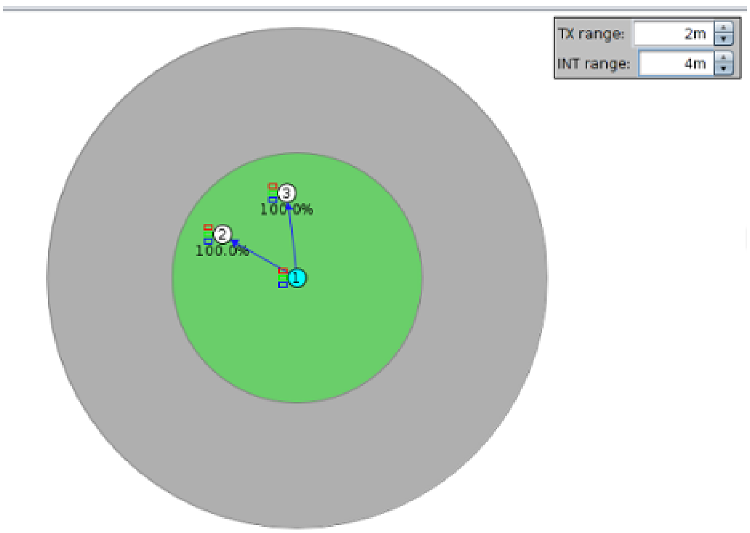

Figure 4.1: Unit disk graph model (UDGM) in cooja

In Cooja Unit Disk Graph Model (UDGM) emulates the link failure model. Transmission range and interference range are taken as two different range parameters. By increasing the radio power we can increase the radio ranges. We can change the transmission distance, as well as the success ratio.

We can set transmission range and interference range independently. As radio power increases both radios ranges increases. By UDGM model transmission and reception, ratio can also be configured. The figure contains three nodes, node 1 and node 2 are transmitters where node 3 acts as a receiver. For transmitters, we have set success ratio 100% for transmitter and receiver both. The bigger green circle is transmission range of receiver node 3 and gray circle denotes collision with other radios. In this simulation environment, Zolertia Z1 motes are emulated.

Network Setup The analysis is based on star network (single-hop scenario) where the sink is the PAN coordinator and all other nodes work with a duty cycle as a beacon-enabled mode. The nodes are kept on the periphery of circle keeping sink at the center, 10m far from it. hidden node problem is excluded by setting all nodes in the collision range of each other.

4.4 Performance Evaluation

Firstly we observe the delivery ratio by increasing a number of nodes in the network. One assumption is made that sensor nodes are always active. The results are taken for periodic and non-periodic traffic for AKC ON/OFF and beacon enabled and non-beacon mode. Random traffic is generated according to a Poisson process.

Results show that when traffic pattern is random with ACK OFF and non-beacon mode the delivery ratio is close to 100%. In beacon enabled mode the delivery ratio drops badly. For periodic traffic, the delivery ratio is even worst. For 50 nodes the delivery ratio floats around 10%-20% for periodic and random traffic

For random traffic, the results are very different for beacon enabled and non-beacon mode. When nodes are always active they transmit packets just after packet creation. This process is spread over beacon interval time for all nodes and there is less chance of contention. In a beacon enabled mode data transfer takes place at the beginning of next active period irrespective of their packet generation time.

The figure sows that IEEE 802.15.4 MAC is not able to manage nodes contending for channel access even in a smaller network. Finally, it clearly shows that this MAC is not suitable for multi-hop topology.

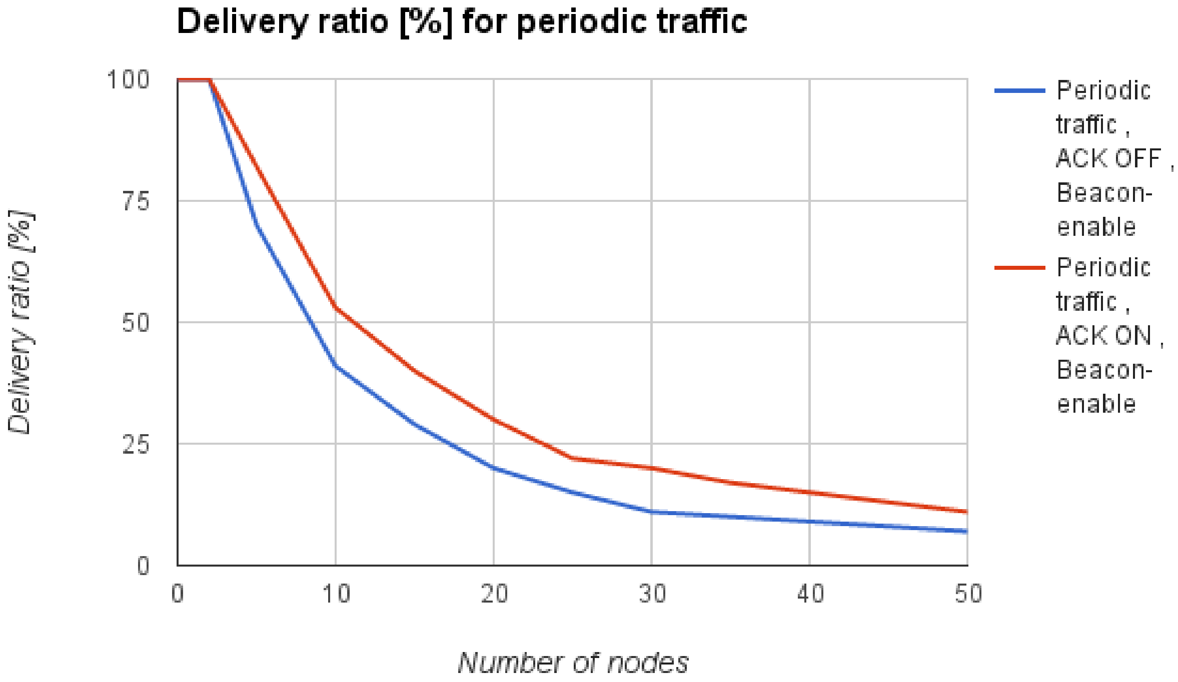

Figure 4.2: Delivery ratio for periodic traffic in beacon-enabled mode

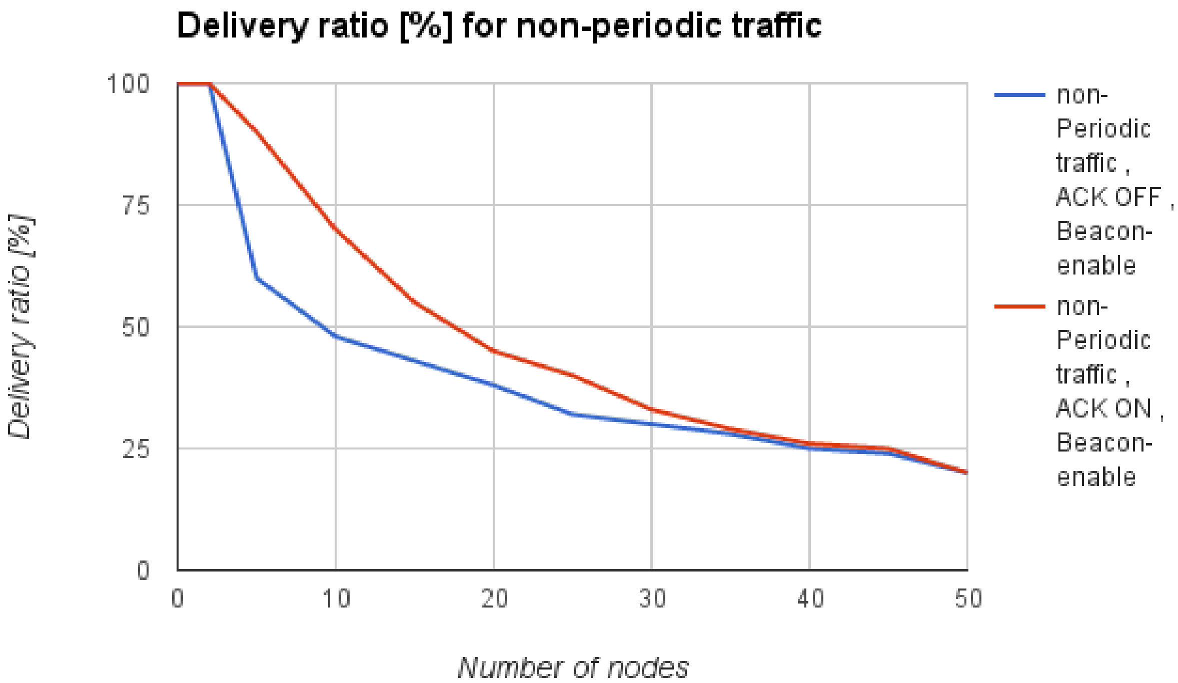

Figure 4.3: Delivery ratio for non-periodic traffic in beacon-enabled mode

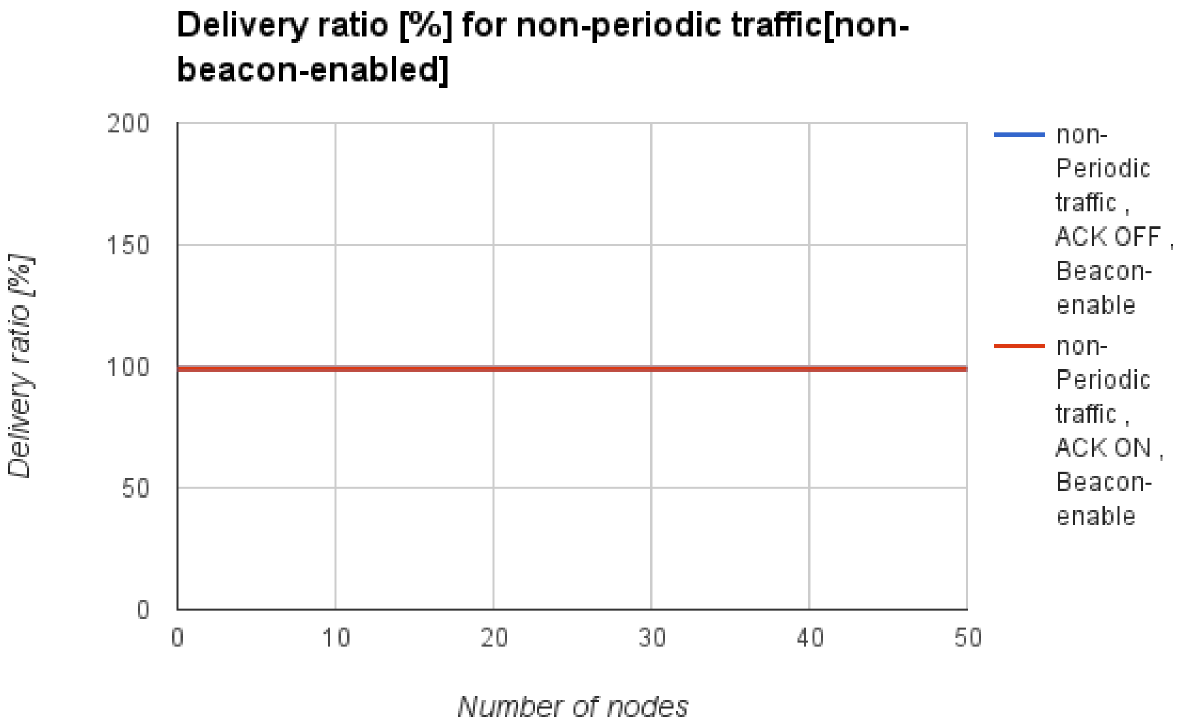

Figure 4.4: Delivery ratio non-periodic traffic in non-beacon-enabled mode

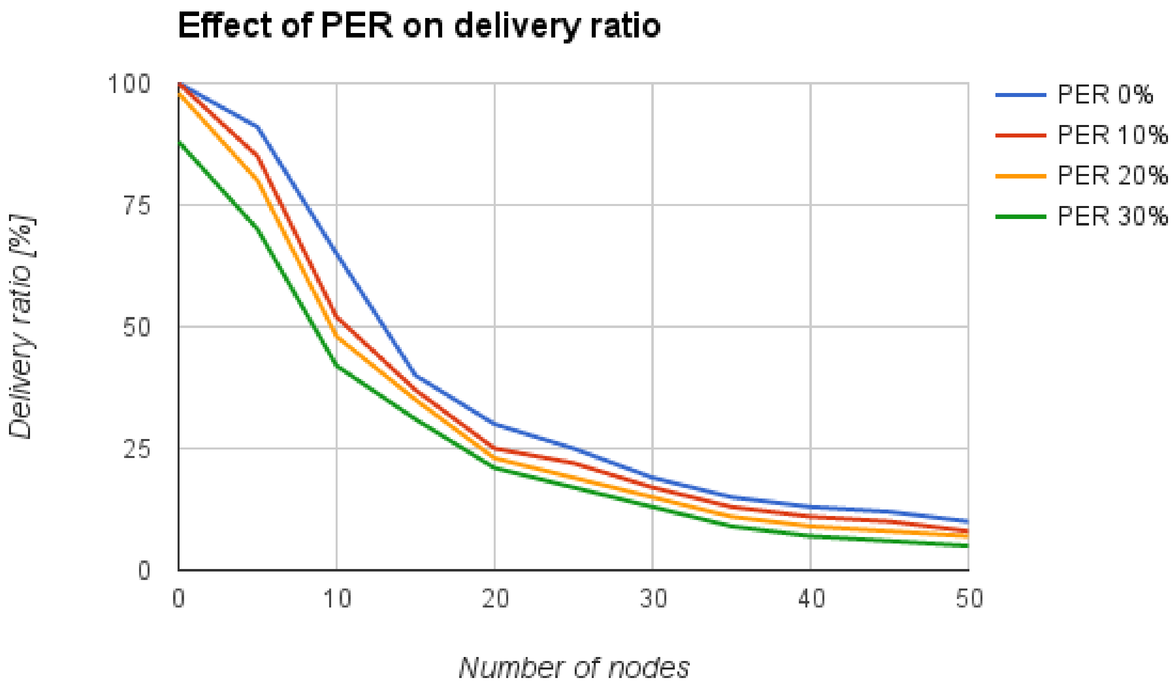

Figure 4.5: Impact of packet error rate on the delivery ratio

The figure shows as PER increases MAC unreliability problem increases. The PER value varies from 10% to 30% .The main reason is nodes have to retransmit more frames and ultimately contention increases at starting of the active period. The same scenario, even if umber of nodes is very low the effect is very high. As we increase nodes in network with increasing PER packets requiring retransmission increases.

Maximum number of backoff stages

To measure the performance of the CSMA algorithm used in 802.15.4 various experiments are done at keeping all other parameters at default value except one. This section shows the effect of macMaxBackoff on the delivery ratio, latency and energy efficiency. The parameter defines the maximum number of backoff stages allowed. When a medium is found busy the CSMA/CA algorithm increases the parameter value. Concurrently the backoff window is doubled at each stage until the maximum backoff window value. For evaluation, the backoff stages are taken from 0-10 , but in standard it is 0-5 allowed.

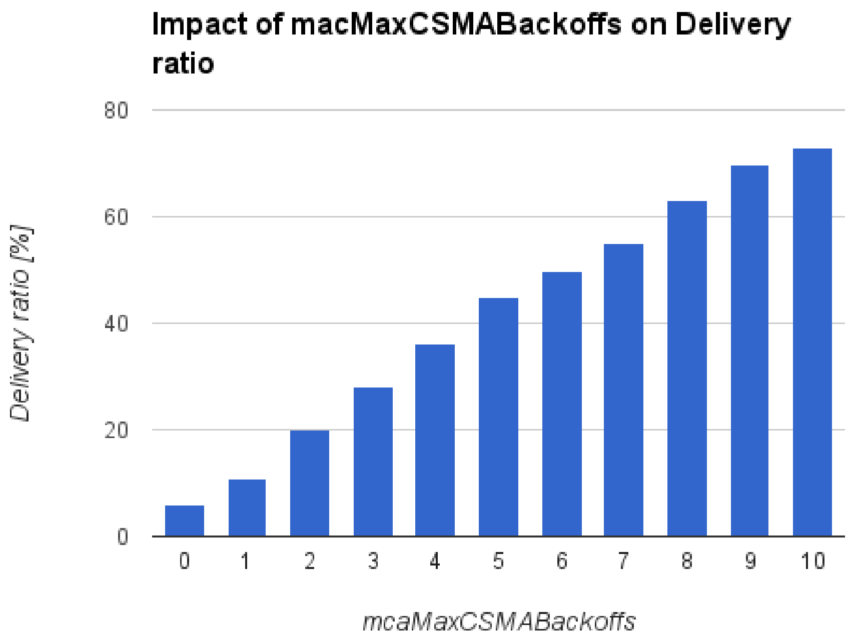

Figure 4.6: Impact-of-macMaxCSMABackoffs-on-delivery-ratio.png

From results, it is clearly observed that delivery ratio increases by increasing allowed backoff stages and the average message latency also increases. The average energy con-

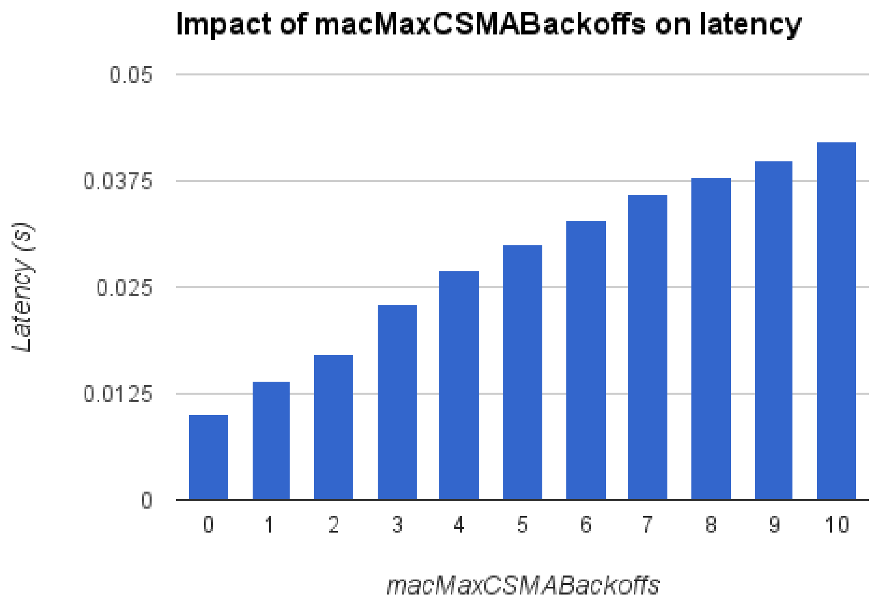

Figure 4.7: Impact of macMaxCSMABackoffs on latency

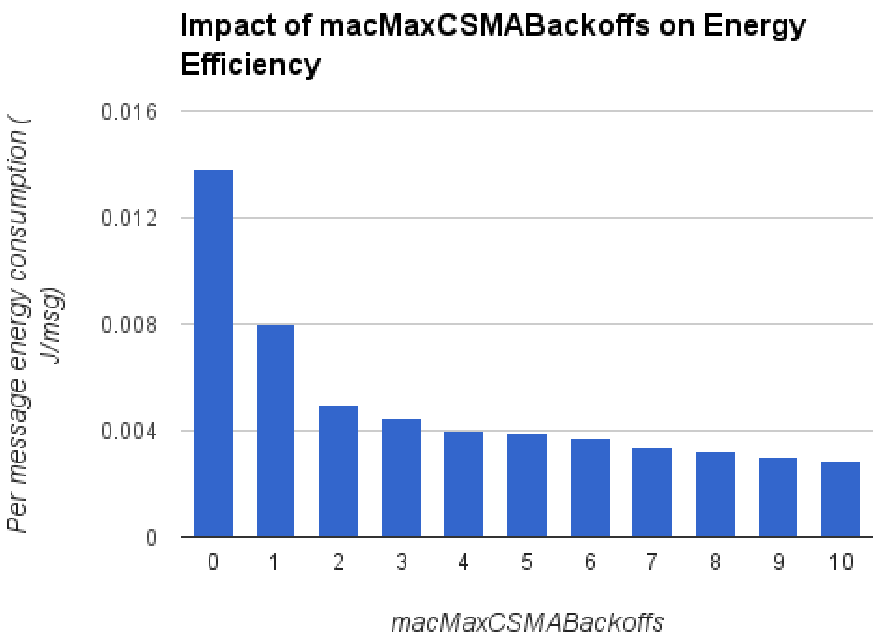

Figure 4.8: Impact of macMaxCSMABackoffs on energy efficiency

sumed per message decreases with increasing the value of allowed backoff stages. This is because a larger number of messages are successfully transmitted. Hence, senor node can use their energy efficiently.

At last by increasing the macMaxCSMABackoffs value gives better network performance but the delivery ratio is still less than 80% even 10 stages are allowed and it is not really allowed in a standard.

Maximum backoff window

This section analyzes the impact of Maximum backoff window size. The value is taken from 3 to 10 where the standard allows 3-8. All other parameters are set to default value.

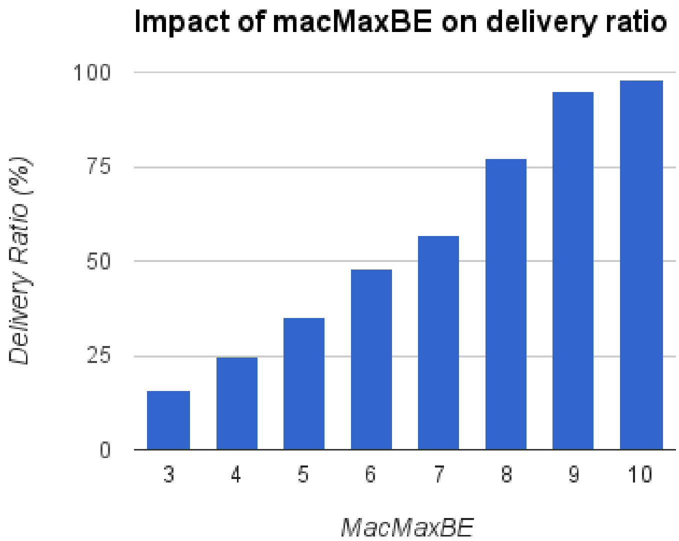

Figure 4.9: Impact of macMaxBE on delivery ratio

Results show that the delivery ratio increases when window size increases and it is close to 100% when macMaxBE 9. By increasing window size the average energy consumed per message decreases. But the average latency increases due to the larger number of a message can be delivered to sink. It is advisable to set maxBE widow so that collisions can be avoided at initial stages. Nodes can choose a random value from a wide range and collision possibility decreases.

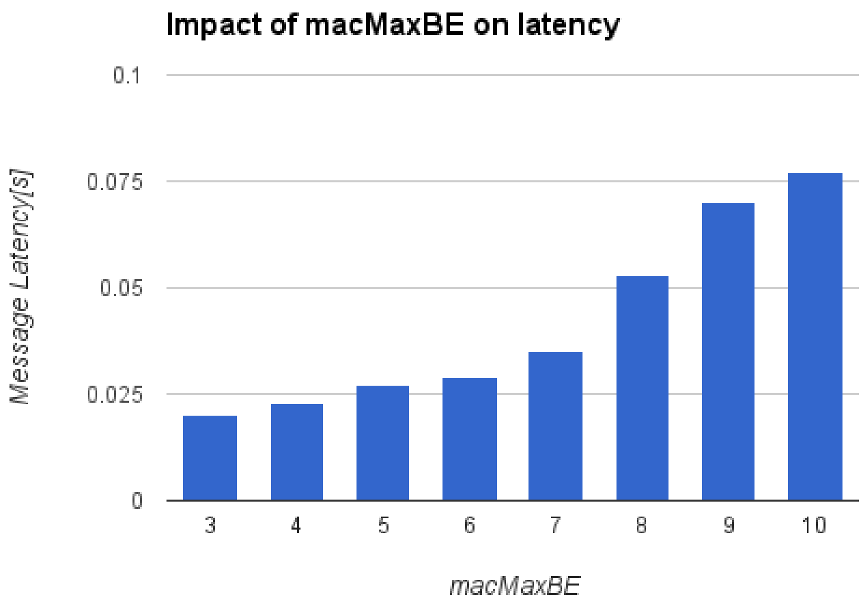

Figure 4.10: Impact of macMaxBE on latency

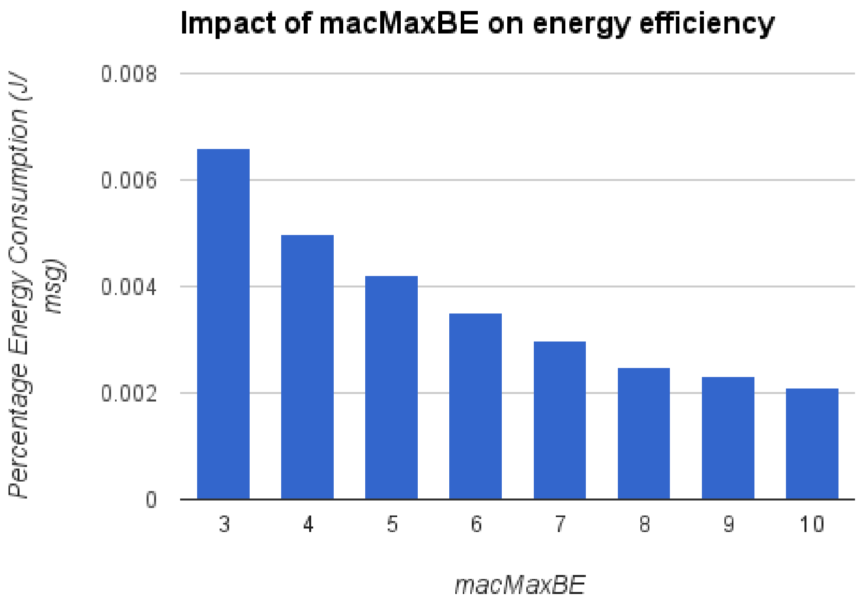

Figure 4.11: Impact of macMaxBE on energy efficiency

Chapter 5

IEEE 802.15.4e

Standard The IEEE 802.15.4e Task Group (TG4e) was created to define an MAC enhancement to the existing standard 802.15.4-2011 [14]. This enhancement is intended to have better results in real-time industrial applications. Industrial applications have the crucial requirement that is not properly addressed by the older standard. Hardware compatibility is completely maintained in newly developed standard. The IEEE 802.15.4e implements modification only on MAC layer the PHY layer is uninterrupted.

5.1 IEEE 802.15.4E with Time Slotted Channel Hopping

The time slotted access proposed in IEEE 802.15.4 combined with channel hopping technique is defined in TSCH protocol. This technique reuses time and channel frequency which is well suitable for a multi-hop network. Rather than superframe structure slot frame structure is adopted in this standard. The length of single slot kept at enough length for maximum length packet transmission and acknowledgment transmission. A single slot can be used by more than one communicating node pairs by using different channel offset. Thus, network capacity is increased by reusing channel frequency.

One another advantage of using different frequency is that it reduces the effects of interference and multipath fading. Standard supports dedicated and shared cells. In figure B A and C A are shared slots .A simple backoff scheme is applied at shared cells in the occasion of a collision. The communication link is defined in a pairwise manner with specifying the direction of communication, slot, and channel offset in a given slot-frame. So

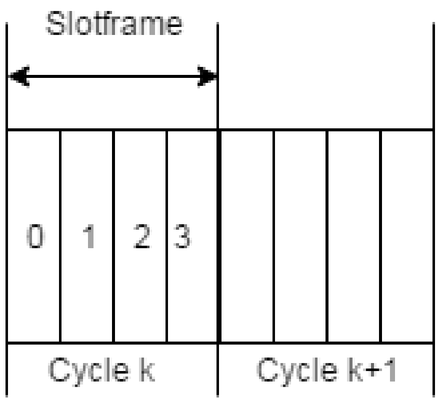

Figure 5.1: A slotframe with 4-slots

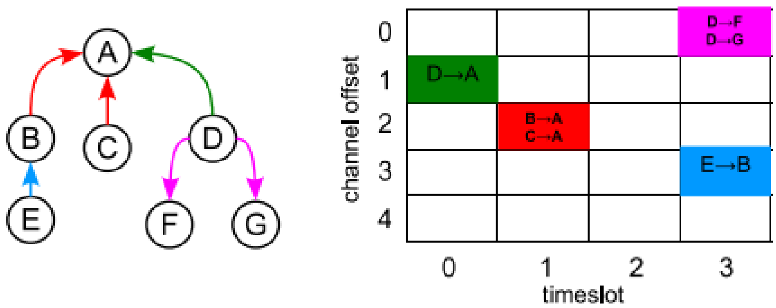

Figure 5.2: Network topology with dedicated and shared links

the communication link is identified as (t,chOf) that is slot and channel offset respectively. Further, the channel offset is mapped or translated to frequency by the following function.

$$f = F(ASN + chOf) mod nch \tag{5.1}$$

$$ASN = (kS + t) \tag{5.2}$$

ASN indicates Absolute Slot Number that defines the total slots gone since network deployment time. S defines slot frame size and k the slot frame cycle.

The function F returns a table containing the set of available channels. The size of a table is defined by the number of available physical frequencies. In an IEEE 802.15.4e network, maximum 16 channels can be used for any type of communication. Thus, transmission going on at same link can be carried on different physical frequencies in successive k slot frame cycles.

5.1.1 Synchronization and Network Formation

TSCH follows a slot-frame structure where every node has information about what to perform at every slot. There are two types of slots that are dedicated and shared slots. For nodes not having channel can compete in shared slots and in dedicated slot pairwise communication between node can take place without the interference of other nodes. In order to actively participate in this TSCH based network node stays active for

- Receive Beacon frames
- Listen during shared slots if any transmission is dedicated to them
- Stay active in dedicated slots. There can be transmission or reception of data frames.

Nodes not participating in dedicated slots can go to sleep stage and save energy.

A PAN coordinator also called as TSCH PAN advertises Enhanced Beacons EB to broadcast network presence. By receiving EB device sends joining request EBR to the advertising device. A device that wants to join the network begins passively or actively that is by using a preferred channel or by scanning for a network. After adding new mote to the network, the adviser sets slot-frames and links between newly added mote and other member motes. The slot-frames and links can be deleted or modified later on. An activated and synchronized FFD can send EBs, to announce network presence. The rate of beacon advertisement is decided by higher layer depending upon network size, energy efficiency, and how fast network formation is needed. In this protocol, device-to-device synchronization is a must in order to carry on connectivity with neighbors. To maintain synchronization receiver calculates the difference between actual and expected arrival times and tunes its clock to stay synchronized with sender with the help of acknowledgment mechanism.

5.1.2 TSCH PAN Formation

Like IEEE 802.15.4 TSCH network consists two types of devices namely FFD and RFD. One of the FFD becomes PAN coordinator. FFD can be a coordinator or PAN coordinator or simple device with higher functionalities than RFD. After activated and became

PAN coordinator an FFD advertises EB. EBs are TSCH frames containing following information.

- Information for Synchronization, helps new devices to synchronize to the network
- Information for Channel hopping helps new devices to learn the channel hopping sequence
- Information for Timeslot that indicates when to expect a frame transmission and when to send an acknowledgment
- Information for Initial link and slot frame that allows new devices to know:
  (i) At what time node has to listen for transmissions from the advertising device, and
  (ii) when to transmit to the advertising device

When a new device wants to join the network it starts scanning for EB. After successful reception of EB, it initializes slot-frame, links and synchronizes itself by exploring information in the EB. Now the device is connected to a network and switched to TSCH mode. To allocate communication resources device goes through a procedure. To authenticate the joining device, configure encryption keys, and configure routing information security handshake is included to this procedure.After successfully joined the network device advertise EB to indicate network presence. The efficient way is to let FFD advertise EB. The rate of advertising should also take care. It should be large enough that new device can join with less delay and it should less enough to maintain energy efficiency.

Chapter 6

Proposed Appraoch

As TSCH is an MAC improvement of IEEE 802.15.4 MAC protocol, still it is power inefficient. The beacon mechanism requires more energy in newer standard also because nodes have to stay awake to receive beacons. Further nodes need to stay awake in shared slots. To observe the energy efficiency network topology is set up with two intermediate nodes, one coordinator node, and one sensor node. The coordinator generates beacon frames and broadcasts it. After synchronizing to network intermediate node sends beacon frame, it forwards all scheduling or joining requests to a coordinator. When a sensor node wants to join the request it starts listening channel for beacon frame to know slot frame structure and information about shared and dedicated slots. The node sends an association request during shared slots. After receiving request intermediate node forwards it to a coordinator. As the response of joining request, coordinator sends an association response having information about dedicated link between the sensor node and intermediate node.

It takes the 40s or more to receive a beacon for a node from initial boots to hear the first beacon. To receive beacon the radio is on continuously. The receive mode operates on 20 mA results in large power consumption for connection setup. This amount is larger compared to communication and synchronization process.

More energy consumed to receive a beacon is because of beacons are sent over any of the 16 channels. There is no fix channel where beacon advertisement takes place.

This problem can be solved by selecting fixed number of channels for beacon transmission. The maximum connection setup time was reduced from 120 seconds to below

10 seconds.

After connected to network nodes do not stop receiving beacons, It receives beacons to check shared slots for broadcast transmission and to check dedicated slot for unicast transmission. Proposed approaches.

- The number of beacon channels are fixed for 3 known channels rather than searching beacons over 16 channels.
- When there is no data to transmit the sensor node decides to skip listening to shared slots.
- Node can skip entire slot frame when there is no data to transmit.

6.1 Performance Evaluation

TSCH network formation process depends on policy used to announce the network presence. Which is achieved by advertising enhanced beacon message (EB)? The standard does not guide how to advertise these message ,it is decided by an upper layer of MAC.

The device has to listen to channel continuously by keeping the radio on. The joining time is a considerable candidate of energy consumption.

The figure shows that the average joining time linearly increases with an increase in a number of channel frequencies used for advertisement. The channel offset must be less than or equal to the umber of available channel frequencies, as it is a numeric indication of the channel [0-15]. The figure shows that if fewer channels are used for EB advertisement, the average joining time reduces significantly. For this, the joining nodes are aware of EB advertising frequencies.

As we fix some channel as beacon advertisement channels, CPU and radio duty cycles reduce. The effect of such a reduction is minimum due to average saving is minimal over a long runtime of the network.

When the whole slot frame is skipped the CPU and radio duty cycle reduces sharply. The reason is node is not awake for some slot frames so it reduces the duty cycle.

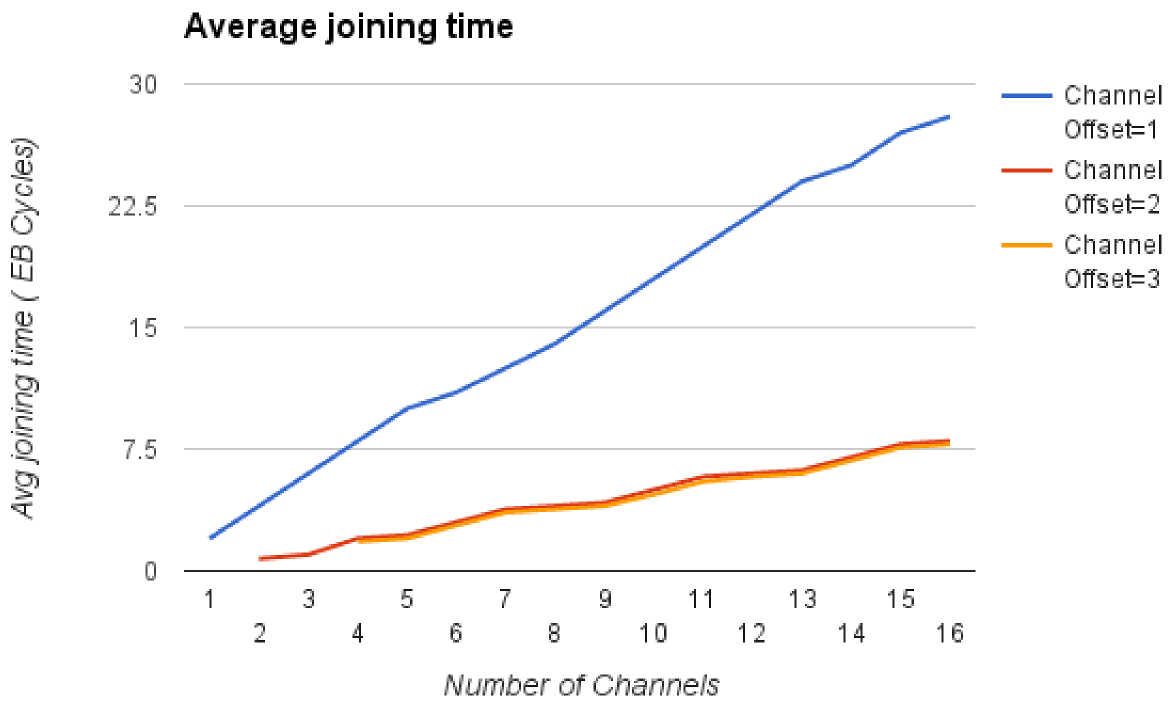

Figure 6.1: Averge joining time by fixing EB advertisemsnt channels

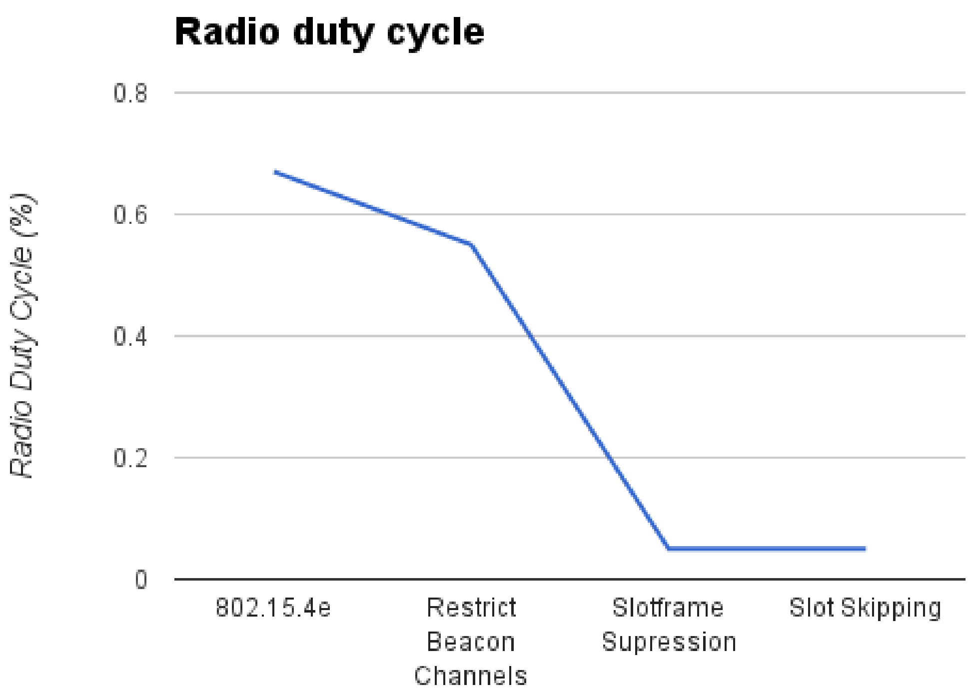

Figure 6.2: Radio duty cycle

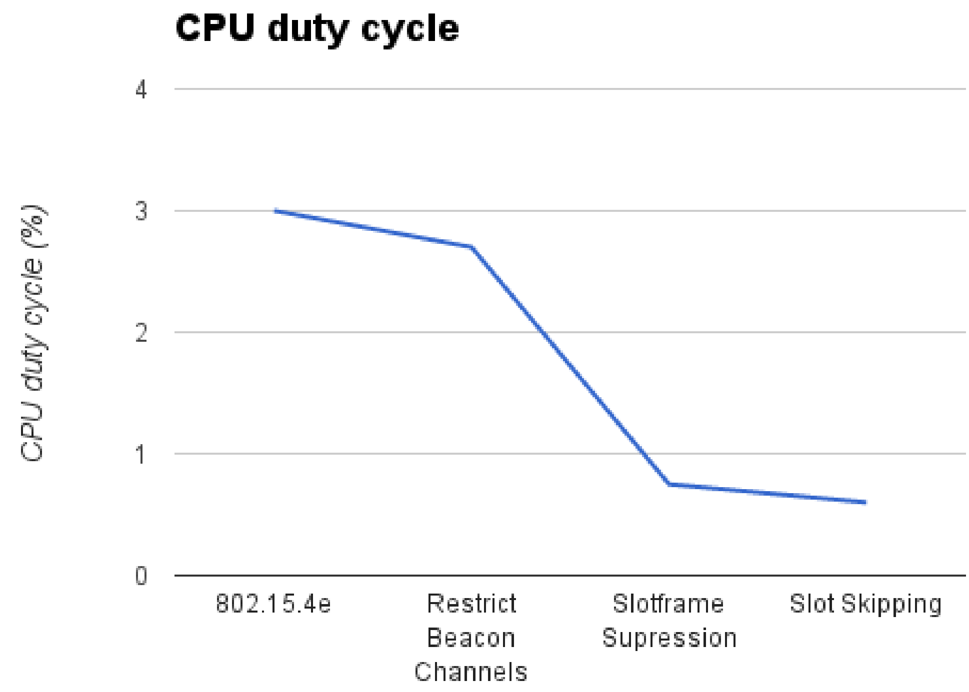

Figure 6.3: CPU duty cycle

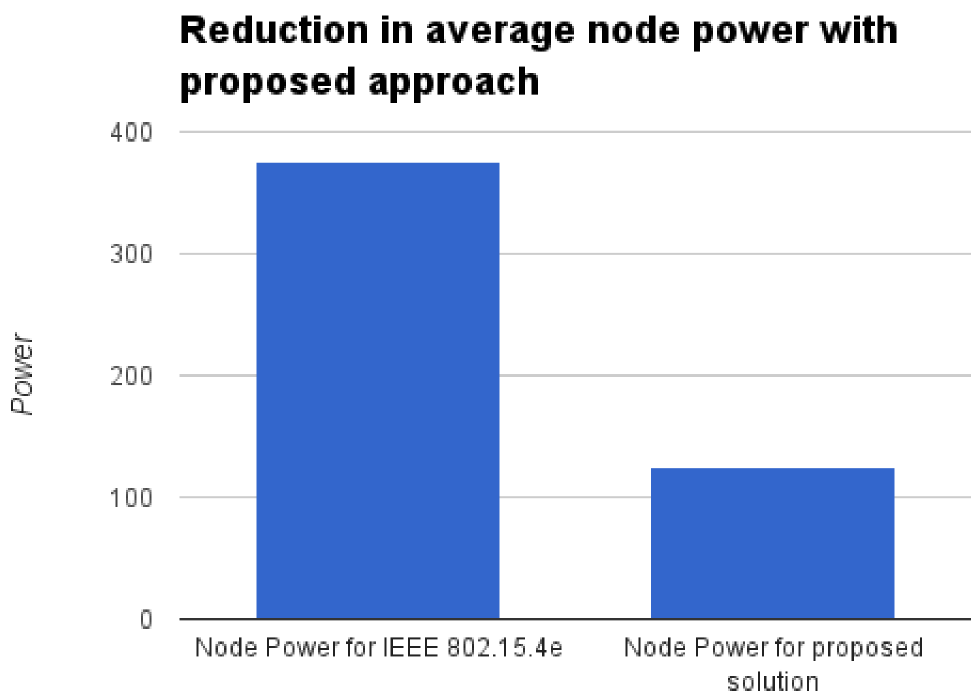

Figure 6.4: Reduction in average node power with proposed approach

As it is clearly visible the effect of slot skipping of shared slot is very negligible because comparing with slot frame, it is larger in time units so the effect is visibly large.

The results of 6.3 show that with proposed approach the considerable amount of average node power is saved.

Chapter 7

Conclusion

The thesis is based on providing QoS to the wireless sensor network. It starts with introducing sensor network and factors affecting to provide QoS to a network. IEEE 802.15 standard is specifically designed for wireless PAN. Where the task group 4 of this standard is working on low rate wireless PAN. MAC superframe structure and its functioning are discussed. Due to severe problem of unreliability, IEEE 802.15.4 is not suitable for real-time application where reliability is a major constraint. IEEE 802.15.4e is MAC enhancement of the previous standard designed by task group 4e of IEEE 802.15 standard. The standard is efficient compared to IEEE 802.15.4, but there are some issues to be solved. One of the major issues is power consumption at node startup time. The proposed approach reduces the overall node power consumption by suggesting three solutions. The radio and CPU duty cycle reduce about 2.7% and the power consumption is less than half power required initially.

Bibliography

[1] I. . W. Group *et al.*, "Ieee standard for local and metropolitan area networkspart 15.4: Low-rate wireless personal area networks (lr-wpans)," *IEEE Std*, vol. 802, pp. 4–2011, 2011.

[2] A. Dunkels, B. Grönvall, and T. Voigt, "Contiki-a lightweight and flexible operating system for tiny networked sensors," in *Local Computer Networks, 2004. 29th Annual IEEE International Conference on*, pp. 455–462, IEEE, 2004.

[3] M. A. M. Vieira, C. N. Coelho Jr, D. da Silva, and J. M. da Mata, "Survey on wireless sensor network devices," in *Emerging Technologies and Factory Automation, 2003. Proceedings. ETFA'03. IEEE Conference*, vol. 1, pp. 537–544, IEEE, 2003.

[4] M. Kumar, K. Pandey, and M. M. Sharma, "Survey on wireless sensor networks using mac protocol," in *Industrial and Information Systems (ICIIS), 2014 9th International Conference on*, pp. 1–6, IEEE, 2014.

[5] I. F. Akyildiz, T. Melodia, and K. R. Chowdhury, "A survey on wireless multimedia sensor networks," *Computer networks*, vol. 51, no. 4, pp. 921–960, 2007.

[6] G. Sakthidharan and S. Chitra, "A survey on wireless sensor network: An application perspective," in *Computer Communication and Informatics (ICCCI), 2012 International Conference on*, pp. 1–5, IEEE, 2012.

[7] S. Misra, M. Reisslein, and G. Xue, "A survey of multimedia streaming in wireless sensor networks," *Communications Surveys & Tutorials, IEEE*, vol. 10, no. 4, pp. 18–39, 2008.

[8] M. A. Yigitel, O. D. Incel, and C. Ersoy, "Design and implementation of a qos-aware mac protocol for wireless multimedia sensor networks," *Computer Communications*, vol. 34, no. 16, pp. 1991–2001, 2011.

[9] M. Souil, *Contribution to quality of service in wireless sensor networks.* PhD thesis, Université de Technologie de Compiègne, 2013.

[10] S. C. Ergen, "Zigbee/ieee 802.15. 4 summary," *UC Berkeley, September*, vol. 10, p. 17, 2004.

[11] E. M. Leão, *Supporting Real-Time Communication in Energy Efficient Large-Scale Wireless Sensor Networks.* PhD thesis, UNIVERSIDADE DO PORTO, 2013.

[12] M. Petrova, J. Riihijärvi, P. Mähönen, and S. Labella, "Performance study of ieee 802.15. 4 using measurements and simulations," in *Wireless communications and networking conference, 2006. WCNC 2006. IEEE*, vol. 1, pp. 487–492, IEEE, 2006.

[13] T. Kalaivani, A. Allirani, and P. Priya, "A survey on zigbee based wireless sensor networks in agriculture," in *Trendz in Information Sciences and Computing (TISC), 2011 3rd International Conference on*, pp. 85–89, IEEE, 2011.

[14] F. Chen, R. German, and F. Dressler, "Towards ieee 802.15. 4e: a study of performance aspects," in *Pervasive Computing and Communications Workshops (PERCOM Workshops), 2010 8th IEEE International Conference on*, pp. 68–73, IEEE, 2010.