PERFORMANCE ANALYSIS OF IEEE 802.15.4 BASED WIRELESS SENSOR NETWORKS

Nivetha Mahalakshmi B
Sri Krishna College of Engineering and Technology ,Coimbatore, India

Abstract: **The objective of my current work is to put forward an analytical model of the performance of the IEEE 802.15.4 wireless sensor networks. The WSN's have witnessed explosive growth in the recent past because of their position independent sensing capabilities even in toxic and inaccessible regions to humans, the low cost of sensors and very long field lifetime attributed to their low power consumption. WSN's may be formed by a few or large number of network sensing nodes. The IEEE 802.15.4 based wireless sensor networks can support a maximum of 250Kbps for 2.4 GHz bandwidth. WSN's can therefore be employed in those areas where any phenomenon (like intrusion detection or health care monitoring) has to be sensed and the packets are generated at a very low data rate. However the standard has limitations on network as the load increases. This paper aims at improving the performance of 802.15.4 hence providing better support for high bandwidth applications and also providing reliable Quality of Service.**

Keywords: Wireless Sensor Networks, WSN, Bandwidth, Packets, Quality of Service

1. INTRODUCTION

The IEEE 802.15.4 protocol specifies the Medium Access Control (MAC) sub-layer and physical layer for Low-Rate Wireless Private Area Networks (LR-WPAN). Even though this standard was not specifically developed for wireless sensor networks, it is intended to be suitable for them since sensor networks can be built up from LRWPANs. In fact, the IEEE 802.15.4 protocol targets low data rate, low power consumption, low cost wireless networking, with typically fits the requirements of sensor network. The IEEE 802.15.4 protocol is very much associated with the ZigBee protocol.

2. LITERATURE SURVEY

2.1 NETWORK DEVICES

According to the IEEE 802.15.4 standard, a LR-WPAN supports two different types of devices:

Full Function Device (FFD): a FFD is a device that can support three operation modes, serving as:

- A *Personal Area Network (PAN) Coordinator*: the principal controller of the PAN. This device identifies its own network, to which other devices may be associated.
- A *Coordinator*: provides synchronization services through the transmission of beacons. Such a coordinator must be associated to a PAN coordinator and does not create its own network.
- A simple *device*: a device which does not implement the previous functionalities.

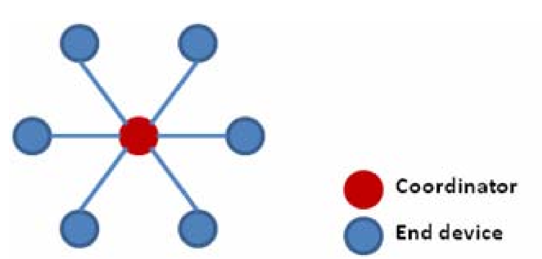
Reduced Function Device (RFD): the RFD is a device operating with minimal implementation of the IEEE 802.15.4 protocol. An RFD is intended for applications that are extremely simple, such as a light switch or a passive infrared sensor; they do not have the need to send large amounts of data and may only associate with a single FFD at a time.

A LR-WPAN must include at least one FFD acting as a PAN coordinator that provides global synchronization services to the network and manages potential FFDs and RFDs

2.2 NETWORK TOPOLOGIES

The Star Topology:

In the star topology a unique node operates as a PAN coordinator. For instance, if an FFD is activated it may establish its own network and become its PAN coordinator. The PAN coordinator chooses a PAN identifier, which is not currently used by any other network in the sphere of influence. The communication paradigm is the star topology is centralized i.e., each device (FFD or RFD) joining the network and willing to communicate with other devices must send its data to the PAN coordinator, which dispatch them to the adequate destination devices. Due to the power-consuming tasks of the PAN coordinator in the star topology, the IEEE 802.15.4 standard mentions that the PAN coordinator may be mains powered while other devices are more likely to be battery powered.



3 .PHYSICAL LAYER OF IEEE 802.15.4

The physical layer of the IEEE 802.15.4 is in charge of the following tasks:

• *Activation and deactivation of the radio transceiver:*
• *Energy Detection (ED) within the current channel*

It is an estimation of the received signal power within the bandwidth of an IEEE 802.15.4 channel. This task does not make any signal identification or decoding on the channel. The energy detection time should be equal to 8 symbol periods. This measurement is typically used by the network layer as a part of channel selection algorithm or for the purpose of Clear Channel Assessment (CCA), to determine if the channel is busy or idle.

• *Link Quality Indication* (*LQI*)

The LQI measurement characterizes the Strength or Quality of a received packet. It measures the quality of a received signal on a link.

• *Clear Channel Assessment* (*CCA*)

This operation is responsible for reporting the medium activity state: busy or idle. The CCA is performed in three operational modes:

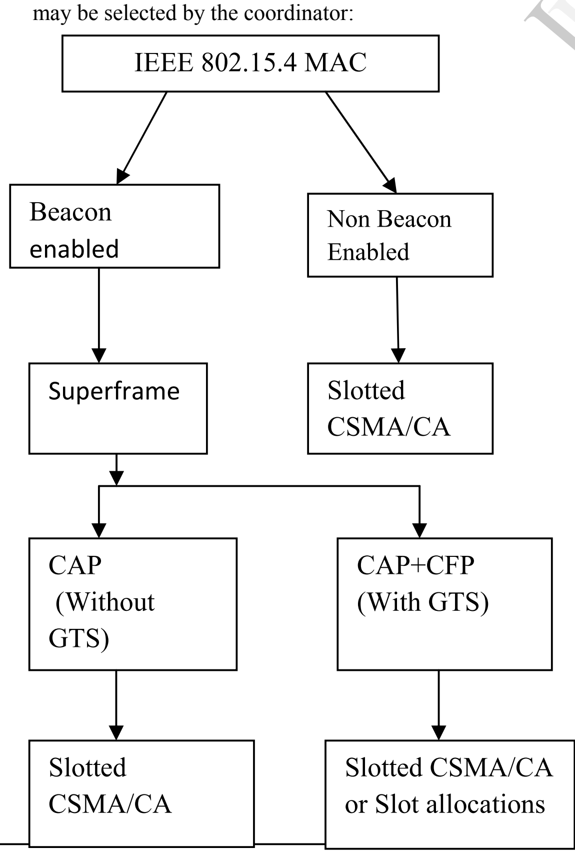
- *Energy Detection mode*: the CCA reports a busy medium if the detected energy is above the ED threshold.
- *Carrier Sense mode*: The CCA reports a busy medium only is it detects a signal with the modulation and the spreading characteristics of IEEE 802.15.4 and which may be higher or lower than the ED threshold.

4. MEDIUM ACCESS CONTROL OF IEEE 802.15.4

The MAC sub-layer of the IEEE 802.15.4 protocol provides an interface between the physical layer and the higher layer protocols of LR-WPANs. The MAC sub-layer of the IEEE 802.15.4 protocol has many common features with the MAC sub-layer of the IEEE 802.11 protocol, such as the use of CSMA/CA (*Carrier Sense Multiple Access / Collision Avoidance*) as a channel access protocol, the support of contention-free and contention-based periods. However, the specification of the IEEE 802.15.4 MAC sub-layer is adapted to the requirements of LR-WPAN

4.1 OPERATIONAL MODES

The MAC protocol supports two operational modes that may be selected by the coordinator:



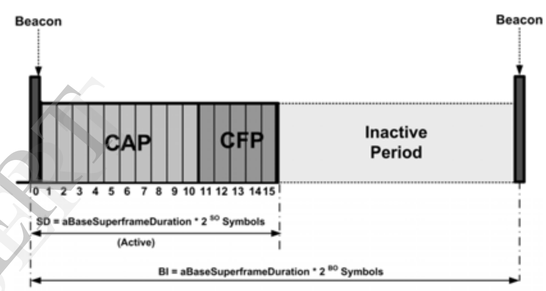
• *Beacon-enabled* mode: Beacons are periodically generated by the coordinator to synchronize attached devices and to identify the PAN.A beacon frame is (the first) part of a superframe, which also embeds all data frames exchanged between the nodes and the PAN coordinator. Data transmissions between nodes are also allowed during the superframe duration.

• *Non Beacon-enabled* mode: In non beacon- enabled mode, the devices can simply send their data by using unslotted CSMA/CA. There is no use of a superframe structure in this mode.

4.2 THE BEACON-ENABLED MODE

When the coordinator selects the beacon-enabled mode, it forces the use of a superframe structure to manage communication between devices (that are associated to the PAN). The format of the superframe is defined by the PAN coordinator and transmitted to other devices inside every beacon frame, which is broadcasted periodically by the PAN coordinator. The superframe is divided into 16 equally sized slots and is followed by a predefined inactive period.

4.3SUPER FRAME FORMAT



Active Period:

Active period consists of two periods Contention Access Period (CAP) and Contention Free Period (CFP). Length of active period is determined by the Super Frame Order. Active Period Length =*aBaseSuperframeDuration * symbols*

Beacon Frames:

Beacons occupy the first slot in Super Frame and are used to synchronize the attached devices, to identify the PAN, and to describe the structure of the super frames. Beacon frames are transmitted periodically to announce the presence of a network.

Contention Access Period (CAP) :

In CAP all the nodes having a packet to transmit compete for the channel and follows Slotted CSMA/CA algorithm. A sufficient portion of the CAP remains for contention-based access of other networked devices or new devices wishing to join the network.

Contention Free Period (CFP) :

CFP is used to allocate slots for the nodes which require low latency i.e., PAN coordinator allocates guaranteed time slots (GTS) for such nodes. A node issues GTS allocation request to the PAN coordinator, which can allocate available GTS to nodes. In the CFP, the node requested for GTS can transmit during its GTS if it is allocated, without any contention with other devices. CFP can be disabled by disabling GTS.

Inactive Period:
In the inactive period, the coordinator may enter a low-power mode and doesn't interact with its PAN which helps in reduced energy consumption and so extends the network lifetime. Inactive period can be remove by setting SuperFrame Order same as Beacon Order i.e., ***BO = SO***

5. ALGORITHM

Key Packet Parameters :
Each packet is characterized by 3 variables NB, CW &BE

Variable	Definition
NB (Number of Backoffs)	*Number of backoffs* the node has underwent while attempting the current transmission, initialized to 0 before every new transmission
CW (Contention Window Length)	*Contention Window Length,* defines the number of backoff periods that needs to be clear of channel activity before the transmission can start.
BE (Backoff Exponent)	*Backoff exponent* is related to how many backoff periods (0to$2^{BE}-1$) a device has to wait before attempting to assess the channel.

5.1UNSLOTTED CSMA/CA ALGORITHM

In both cases, the CSMA/CA algorithm is based on backoff periods, where one backoff period is equal to *aUnitBackoffPeriod* = 20 *Symbols.* In slotted CSMA/CA the backoff period boundaries must be aligned with the superframe slot boundaries where in unslotted CSMA/CA the backoff periods of one device are completely independent of the backoff periods of any other device in a PAN.

Algorithm Flow

i. NB(=0),CW(=1),BE are initialized.
ii. MAC layer shall delay for a random number of backoff periods in the range (0 to 2^BE-1)
iii. MAC will request PHY to perform CCA
iv. *If* the frame transmission and acknowledgment can be completed before the end of the current CAP then MAC sub layer shall proceed *else* it shall wait until the start of the CAP in the next SuperFrame and repeat the evaluation
v. MAC sub layer shall increment both NB and BE by one, ensuring that BE shall be no more than aMaxBE and if NB is greater than maxMaxCSMABackoffs then the packet is discarded else return to step 2. (Channel Busy)
vi. MAC sub layer starts transmission. (Channel Idle)

Overview:
A packet transmission begins with a random backoff (in number of slots, each slot of 20 duration) followed by a CCA.
A CCA failure starts a new backoff process with the backoff exponent raised by one, i.e., to macminBE+1, provided it is lesser than the maximum backoff value given by macmaxBE.
The maximum number of successive CCA failures for the same packet is governed by *macMaxCSMABackoffs*, exceeding which the packet is discarded at the MAC layer.
A successful CCA is followed by the radio turnaround time and packet transmission.
If the receiver successfully receives the packet i.e., without any collision or corruption due to PHY layer noise, the receiver sends an ACK after waiting for the radio turnaround time.
A failed packet reception causes no ACK generation.
The transmitter infers that the packet has failed after waiting for *macAckWaitDuration* and retransmits the packet for a maximum of *aMaxFrameRetries* times before discarding it at the MAC layer.

Assumptions	IEEE 802.15.4
Star Network with sensors at the tips.	Nodes can be anywhere
No Inactive period and CFP (i.e., BO equal to SO and GTSs are disabled).	SuperFrame has both active (CAP + CFP) and inactive periods.
Data requests from nodes to the PAN Coordinator are not considered	Data transfer can be to/from PAN coordinator

6. CALCULATION

Attempt Rate:
Definition: Number of backoffs over the time spent in backoffs (per node basis):

$$\beta = \frac{Number\ of\ attempts\ or\ Backoffs}{Time\ spent\ in\ Backoffs[slots] + CCA}$$

Attempt rate gives the number of attempts made by sensor in a backoff slot i.e., the probability that a sensor attempts in a backoff slot given that it has a packet.
A backoff is followed by CCA and an attempt can be success or failure. A successful attempt involves a frame transmission and failed attempt involves CCA failure and so number of backoffs/attempts is the sum of failed CCA and frames transmitted.

Discard Probability:
Definition: Probability of packet being discarded.

$$Pdiscard = (Frames\ discarded)/(Frames\ transmitted$$

Payload and Plots:
Payload at Application layer is 4 bytes, overheads are set according to standard(20 IP+13MAC+6PHY).

7.ANALYTICAL MODEL FOR 1 NODE

Let us consider a scenario with 1 sensor, so there will be no collisions. As discussed in the CSMA/CA algorithm a successful packet transmission involves Random Backoffs, CCA, turnaround time, packet transmission, turnaround time, ACK packet + IFS.
Random backoffs generated are governed by BE which is incremented every time CCA fails, as we have no collisions BE is not incremented and so random backoffs are always in the range [0,7] and BE=3(mentioned in standard)
In slotted CSMA/CA, for packet transmission to start the channel needs to be clear of activity in two successive CCAs. Each CCA is 8Symbols long and starts at the backoff boundary and after the 2ndCCA we need radio turnaround time, which is 12 symbols long, to change from receiver to transmitter before packet transmission starts, so 1st CCA takes only 8 Symbols in a backoff slot and 2nd CCA starts at the next backoff boundary followed by turnaround time and so 2nd CCA + turnaround time takes 20 Symbols which is 1 slot and so 1st,2nd CCA + turnaround time takes 1.4 slots.
Packet size is 43Bytes and Data rate defined by 802.15.4 for 2.4GHz bandwidth is 250Kbps and so time taken to transmit the packet is (43*8)/(250*1000)=1.376ms . (Each slot is 20Symbols and each symbol takes 16µs and so each slot is 20*16µs=0.32ms)and so 1.376/0.32=4.3 slots. After the packet transmission, sensor waits for the ACK packet and so the state has to be changed from transmitter to receiver which is 12 Symbols = 0.6slots and so the state change can be completed in the last slot of packet transmission, so packet transmission + turnaround time is 5 slots.
ACK packet is 11 bytes and so takes 0.352ms for transmission and 0.352/0.32 is 1.1 slots.After receiving ACK packet, sensor waits for 2 slots (i.e., IFS, Inter Frame Spacing so that MAC sub-layer has sufficient time to process the data received from Physical layer) before attempting again. The first slot in IFS is taken as the last slot in ACK packet as it takes only 2Symbols. So ACK packet + IFS take 3 slots.

Random Backoffs	3.5 slots
2 CCA + Turnaround Time	1.4 slots
Packet Transmission + Turnaround Time	4.9 slots
ACK Packet +IFS	3.1 slots
Total	13 slots

Throughput: 1 packet is transmitted for every 13.5 slots, throughput = 1 packet/13 slots
Attempt Rate: 1 attempt is made in 3.5slot random backoffs and 2slot CCAs, β= (1)/(4.9)=
Discard Probability: For 1 node case there will be no collisions.

RESULTS

We see that changing the backoff parameters (backoff multiplier, ranges of backoff exponent i.e., macMinBE and MaxBE), leads to a higher throughput as compared with the 802.15.4 standard. As the attempt rate (β) increases, probability of a packet collision increases and so throughput decreases. Changing the backoff parameters decreases the attempt rate (β), as and therefore the collisions decrease leading to higher throughput.

FUTURE WORK

As of now only the star topology has been considered for performance evaluation , I wish to extend my work to the tree and cluster tree topology as well. In addition I also wish to make considerations regarding the packet size and the transmitting power of the sensor.

REFERENCES

1. *Performance evaluation of an IEEE 802.15.4 sensor network with a star topology*. **Singh, Chandramani K., Kumar, Anurag and Ameer, P.M.** 2008, Wireless Networks 14, pp. 543–568.

2. *IEEE 802.15.4 for Wireless Sensor Networks: A Technical Overview*
ANIS KOUBAA, MÁRIO ALVES, EDUARDO TOVAR

3. *ZigBee/IEEE 802.15.4 Summary*
Sinem Coleri Ergen

4. *Performance Analysis of IEEE 802.15.4 Beacon-Enabled Mode*. **C.Burati**

Performance analysis of markov modulated IEEE 802.15.4 beacon-enable mode **Dongjie Yin, Tony T. Lee**