Survey on Performance of IEEE 802.15.4 Low Rate - Wireless Personal Area Networks (LR-WPAN)

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Abstract:
Wireless personal area networks are used for relatively short distances. IEEE 802.15.4 standard was introduced in 2003 for wireless personal area networks. It provides low-cost communication, low data-rate with limited battery life and maximum throughput [4]. In this paper we will review various factors for performance evaluation of IEEE 802.15.4 which make it different from various other wireless protocols. Various factor can be like direct and indirect data transmission, CSMA-CA mechanism, data payload size and beacon-enabled mode. On the basis of these factors various performance metrics are evaluated. These metrics are like delivery ratio, received signal strength, and data throughput. It has been evaluated that IEEE 802.15.4 performs better in non-beacon mode rather than in beacon mode. In this paper we will discuss various performance measures of IEEE 802.15.4.

***Keywords*: IEEE 802.15.4, Low Rate –Wireless Personal Area Network (LR-WPAN).**

I. INTRODUCTION

In recent years wireless communication has became vital need. Wireless communication provides mobility and flexibility. Such network helps in accessing network anytime and everywhere. Such networks are easily deployable and forms dynamic network with low cost communication. But there are some restrictions in such network which should be evaluated to improve their performance. These restrictions are like limited battery-life, complexity, cost factor and need of high data throughput. In order to improve the wireless communication in personal area network IEEE 802.15.4 was introduced. It architecture is composed of physical and MAC sub layer [10, 15,16]. It provides low-cost communication, low data rate, improved throughput and low power supply. In this paper we will have a brief overview of IEEE 802.15.4 and various features that will help in evaluating the performance of this standard. And then we will have brief overview of all the performance metric of this standard.

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II Overview of IEEE 802.15.4 LR-WPAN

The IEEE 802.15.4 is a new standard defined for WPAN which provides low-cost communication, low data-rate with limited power consumption. This works for short distance network. It is widely used in building automatic control, industry autoimmunization, monitoring and control of hospital and other fields.
The IEEE 802.15.4 standard defines two layer, physical layer (PHY) and medium access control (MAC) sub layer [1, 3].

1. Network Topology

IEEE 802.15.4 LR-WPAN supports various network topologies like star, tree and mesh networks as shown in Figure 1. They are composed of the Coordinator, the router, and the end device [2, 3].

- Coordinator: - Coordinators are full functional devices (FFD). A full functional device performs routing mechanism, coordination task and sensing task. Only one coordinator is assigned in a network. Its function is to initiate the network and it is the root of the network.

- Router: - Router act as an intermediate router that helps in transmitting data from one device to another. They are also full function devices (FFD).

- End Device: - It is a low-power device which interacts with the parent node which could be either the coordinator or a router. It cannot transmit data from other devices. This allow end device to sleep thus providing a long battery life. They can be either full function device (FFD) or reduced function device (RFD). RFD does not route packets and can only be associated with a single FFD at a time. The RFD can communicate with only an FFD.

In Star topology a coordinator is responsible for the network. All the other devices are end devices and communicate directly with the coordinator. This topology is suitable for networks with a centralized device and for time critical applications.

In Mesh network coordinators are still responsible for the network initiating and maintenance. Router can be used to extend the network. A mesh network should allow full peer-to-peer communication.

Cluster tree is the combination of both star and mesh networks and so it has the properties if both the topologies. In tree network coordinators are still responsible for the network initiating and maintenance. Routers can be used to extend the network. Routers control the flow of data by using hierarchal routing strategies in the network. They also may imply beacon enabled network defined in IEEE 802.15.4 for periodical data transmission.

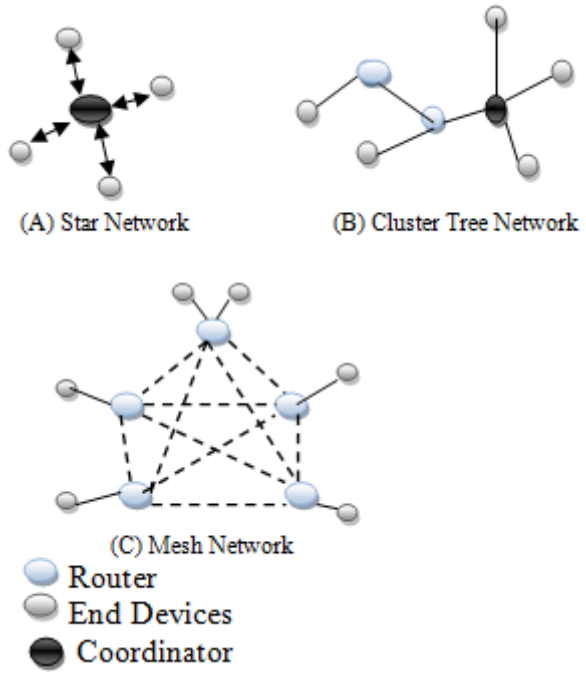

Figure 1. Network Topology

III. Overview of factors effecting performance of IEEE802.15.4

A: Beacon and non-beacon mode.

The IEEE 802.15.4 standard defines physical layer and MAC sub layer [1, 8, 9]. The MAC sub layer can operate either in beacon-enabled mode or non beacon-enabled mode. The coordinator can choose the mode in personal area network (PAN). Beacon-enabled coordinator will send the beacon frame periodically to all the nodes attached to coordinator depending on the beacon interval (B). Beacon synchronizes all the attached nodes in the PAN and defines the superframe structure. Beacon interval is the time between two consecutive beacon frames. Beacon frames consist of active and inactive portion. The active portion is called superframe. Transmission is based on superframes slotted CSMA-CA when in beacon mode and in case of non beacon-enabled mode message in transmitted directly in an unslotted CSMA-CA. Superframe is divided into 16 equally sized slots during which frame transmission takes place, where the first slot is assigned beacon. Active portion of beacon frame consist of beacon, contention access period (CAP) and contention-free period (CFP). Beacon is transmitted at the first slot without the use of CSMA-CA. CAP commence immediately after the beacon. If any device wishes to communicate between two beacons must use slotted CSMA-CA mechanism to compete. CFP follows immediately after the CAP, if it exists and follows till the end of active portion. CFP does not use CSMA-CA mechanism for transmission.

Superframe is evaluated by two parameters beacon order (BO) and superframe order (SO) as shown in figure 2. The beacon interval (BI) which is also known as superframe length and the length of active part called superframe duration (SD) is defined as follows:

$$BI = aBaseSuperframeDuration \times 2^{BO},\ 0 \leq BO \leq 14.$$
$$SD = aBaseSuperframeDuration \times 2^{SO},\ 0 \leq SO \leq 14.$$

Where, *aBaseSuperframeDuration*, the number of symbols forming a superframe when the superframe order is equal to 0, is 960 symbols [11].

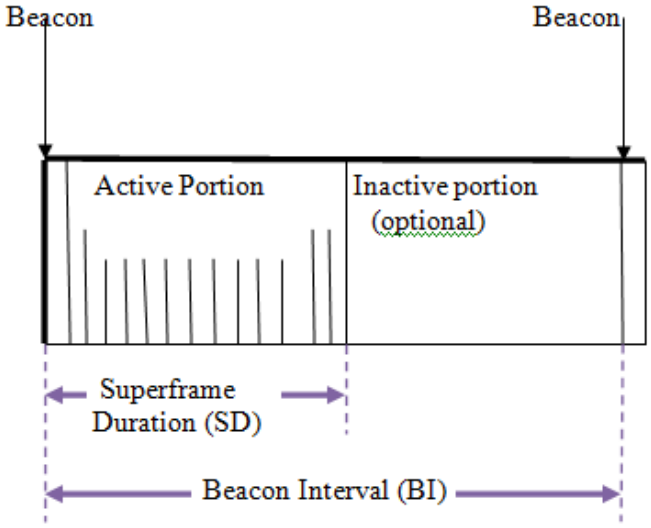

Figure 2. Beacon interval and superframe structure

B: CSMA-CA Mechanism

The CSMA-CA mechanism is used within the CAP. The mechanism is required for sharing the wireless channel. This mechanism is used in two different ways for accessing the wireless channel which are described as follows [11, 14]:

Unslotted CSMA-CA: - This channel access mechanism is used for non beacon enabled frame. When data is needed to b transferred, it senses the channel. If it's found to be idle it transmits the data. If channel is busy then device waits for random backoff time before sending the data. If channel is found busy again, then again it waits for random period before transferring the data

Slotted CSMA-CA.:- This channel access mechanism is used for beacon enabled network. When a device wishes to transmit the data, it locates the boundary of next back off slot and then wait for the random number of back off slot. If the device is idle it transmits the data in the next available back off slot. If channel found busy then it will again wait for random number of back off slot.

C: Data Transmission

Data transmission can be direct or indirect data transmission. It depends on requirement of the beacon network which type of transmission to be used [5, 7].

Direct data transmission: - In this data transmission when data is to transfer it is send to the coordinator first. The data transmission can take place in beacon-enabled and non beacon-enabled network. In beacon-enabled network when a device wishes to transfer the data. It first listens for the network beacon .If beacon is found then device synchronizes with superframe structure. And then data is transferred to the coordinator using slotted CSMA-CA. In case of non beacon-enabled network the data is transferred directly to the coordinator using unslotted CSMA-CA. When data is received by the coordinator, acknowledgement is sent to the device in both the cases after the reception of the data.

Indirect data transmission: - In data transmission mechanism data is transferred from the coordinator to the device. In the beacon-enabled network when the coordinator wishes to send data to a device, it indicates in the network beacon that the data message is pending. The device periodically listens to the network beacon, if a message is pending. If so then it transmits a MAC command requesting the data using the slotted CSMA-CA. When the coordinator receives the successful reception of the message request, it sends the acknowledgement for the confirmation. After that pending message is transferred using slotted CSMA-CA. On successful reception of the message by the device, acknowledgement frame is sent to the coordinator. And then that message is deleted from the list pending message in the beacon. In case of non beacon-enabled network, when a coordinator wishes to transfer data to a device, it stores the data for the appropriate device to make contact and request the data. A device make contact to the coordinator by sending the MAC command requesting the data using unslotted CSMA-CA. then coordinator acknowledges successful reception of the request by sending the acknowledgement frame to the device.
If there is no data to be send, coordinator transmits a data frame with a zero-length payload to indicate that there were no data pending.

IV Performance Evaluation

A: Effects of beacon-enabled mode

Practically, it has been found that in case of non beacon-enabled network data rate is larger than the beacon-enabled network. Figure. 3 show the effective data rate between the coordinator and the device for different number of beacon order. It shows that as beacon order increases, the date rate also gets increased [6].

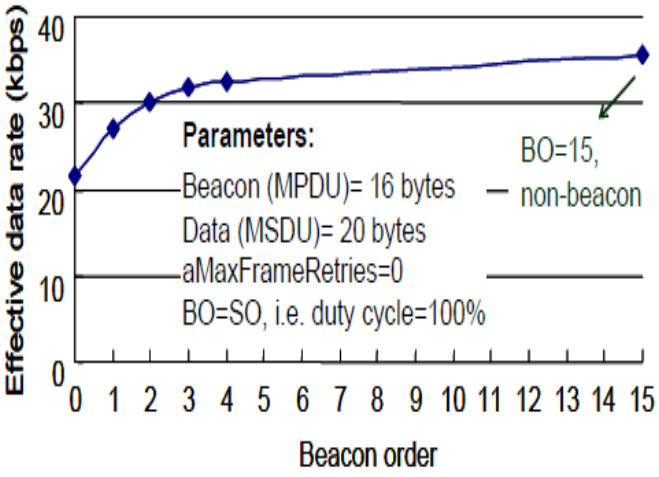

Figure 3. Effective data rate in beacon-enabled network [6]

B: Effects of CSMA-CA mechanism

When the data is transferred using CSMA-CA mechanism sometimes data get lost or corrupted. The data may not get delivered as the channel remains busy dye to heavy traffic. It has been seen experimentally that when devices get increased, the effective data rate and delivery ratio both get decreased due to collision and frequent backoffs. As shown in figure 4 and 5 the effective data rate and delivery ratio get reduced with varied traffic load [13, 14].

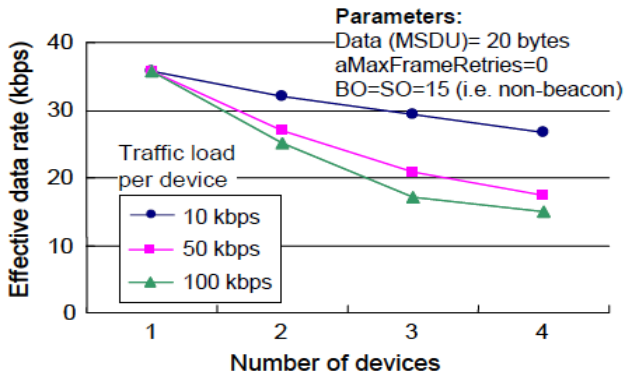

Figure 4. Effective data rate of CSMA-CA with varied traffic load in non beacon-enabled network [8].

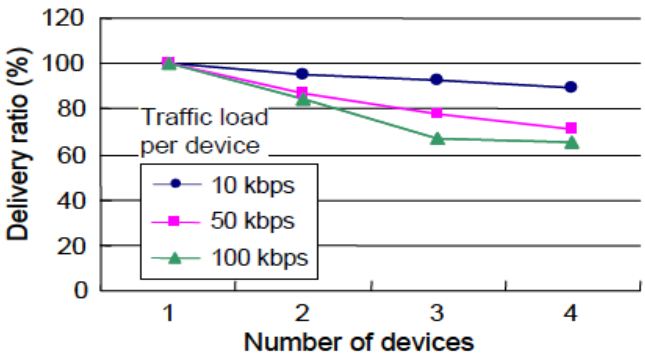

Figure5. Delivery ration of CSMA-CA with varied traffic loads in non beacon-enabled network [8].

C: Effects of Data Transmission model

Data transmission model whether it is direct data transmission or indirect data transmission, there performance is evaluated on the basis of raw data rate [12]. Figure 6 shows raw data rate for both direct and indirect data transmission [8]. There is a slight variation in raw data rate with an average as 153.02 kbps for direct data transmission and 65.59 kbps for indirect data transmission. Here the data rate is greatly reduced in indirect data transmission because of sending the data periodically.

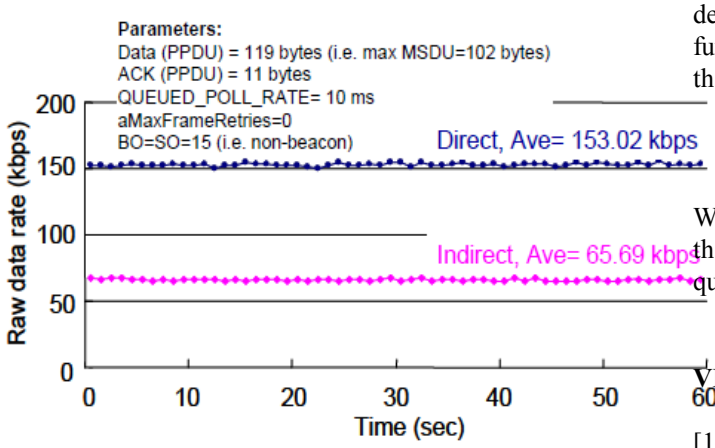

Figure 6. Raw data rate for direct and indirect transmission for non beacon-enabled network [8].

The RSSIs values are different for both the direct and indirect data transmission. Figure 7. Shows the different RSSI values observed experimentally for direct and indirect data transmission [8]. The result can be because of number of factors like environmental disturbance lowering the signal strength.

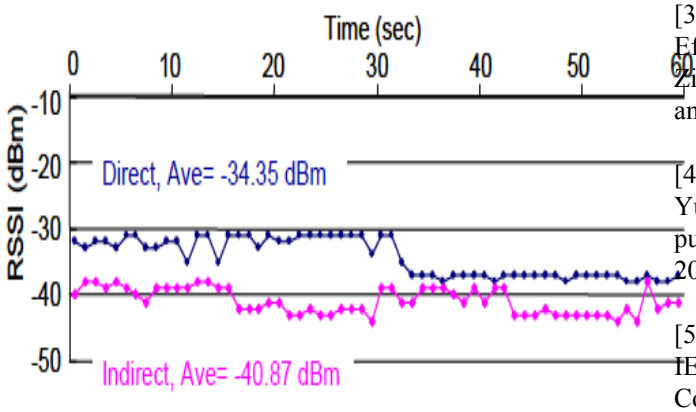

Figure 7. RSSI value for direct and indirect data transmission in non beacon-enabled network [8].

V Conclusion

This paper has shown different aspects of IEEE 802.15.4 standard. This paper has a brief overview of the performance metrics IEEE 802.15.4 for LR-WPAN. This standard is much promising for the short distance network. It has been shown in this paper how various performance metric get affected by different aspect of this standard. All the result has been studied from various authors as per their experiments. All the performance metric can be improved for the successful implementation of IEEE 802.15.4 standard. This standard is very much suitable for low rate-wireless personal area network. It can be easily implied in wireless sensor network. The key focus of our study is exploring the different aspects of standard 802.15.4 low rate - personal area network. In recent times Zigbee has gained popularity in LR-WPAN. The IEEE 802.15.4 based zigbee offers an ideal specification for low data rate and low power consumption applications providing a reliable and cost effective network. These features are promising for various applications like Health care, Fire emergency, traffic management, flood detection, military application and home automation. As a future work we can add security in encryption mechanism in this standard.

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