An IEEE 802.15.4 Wireless Standard simply Works with Star Topology

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ABSTRACT
The new IEEE 802.15.4 shows promise to bring networking in to out lives. Unlike other standard targeting high-or-moderate-data-rate applications, IEEE 802.15.4 is global standard designed for low data rate, low power consumption and Low cost application. This standard will bring many simple, originally Standalone devices in a networks and thus not only open door to an enormous number of new applications, It add's new values to existing applications. One class of application investigated for the IEEE 802.15.4 LR-WPAN (Low Data Rate-Wireless Personal Area Network) standard is wireless for monitoring and control applications. In this paper an analytical performance model is provided for an IEEE 802.15.4 network with a star topology. We first carry out a saturation throughput analysis of the system; i.e., it is assumed that each sensor has an infinite backlog of packets and the throughput of the system is sought. After an analysis of the CSMA/CA MAC that is employed in the standard, and after making a certain decoupling approximation, We identify an enabled Markov renewal process, whose analysis yields a fixed point equation. Solution of this fixed point equation yields certain quantities from which the throughput can be calculated.

1. INTRODUCTION

There are many industrial and home market applications that require long battery lives, low data rates, and less complexity than existing wireless networks. Potential applications include:

- Automation and control: home, factory, warehouse.
- Monitoring: safety, health, environment.
- Situational awareness and precision asset location (PAL):
  military operations, firefighting, real-time tracking of inventory.
- Entertainment: learning games, interactive toys.

Low Rate-Wireless Personal Area Networks (LR-WPANs) are designed to serve these applications with a focus on enabling wireless sensor networks. Although these are low data rate solution aiming at multi-month to multi-year battery life, and very low complexity, the technology needs to be reliable, secure and robust, and needs to meet network performance objectives.

The IEEE 802.15.4 standard has evolved to realize the Physical (PHY) and Multiple Access Control (MAC) layers of such LR-WPANS. The ZigBee alliance has developed the network and upper layers. The overall objective of our work reported here is to analyze the performance of such LR-WPANS for industrial monitoring and control applications. Such applications aim to replace existing wired sensor networks (based, e.g., on the Fieldbus standard) with wireless ad hoc sensor networks. The end to end applications, however, will initially remain unchanged. Hence the concern is whether the wireless network will be able to carry the measurement and alarm traffic with the same level of performance as the wired network.

In this paper we provide the results of our analysis of a star topology sensor network based on the IEEE 802.15.4 standard. Here we limit our work to the situation in which packets flow only from the sensors to the head of the hub of the star (i.e., the PAN coordinator). We first obtain the saturation throughput of the network. Then we provide some results on performance with Poisson arrivals of measurements.

The following figure shows the basic block diagram

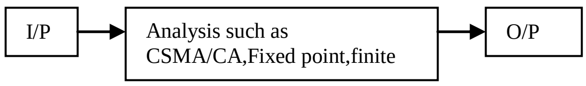

Fig1: basic block diagram

The following is a preview of our main contribution and findings.

1. A fixed point analysis, based on a decoupling approximation as can be developed for IEEE 802.15.4 networks and, it captures the saturation throughput with an error of 3% to 10%
2. The design of the CSMA/CA MAC in IEEE 802.15.4 is such that the aggregate saturation throughput decreases with the number of nodes. We show that, staying within the standard framework, it is possible to modify the backoff parameters so that the saturation throughput is not very sensitive to the number of nodes. It is also found that packet discard probabilities are much reduced after these modifications.

2. ARCHITECTURE AND SPECIFICATION

Low rate Wireless Personal area network consist of two types of devices: full function device (FFD) and reduced function device (RFD). An FFD can talk to RFDs or other FFDs, while a RFD can talk only to FFD.

LR-WPAN consist of three type of nodes depending on their responsibilities

1. **PAN Coordinator***:* It is the primary coordinator of the network and is used to initiate, maintain, terminate, or route communication around the network. It must be an FFD.
2. **Coordinator:** All the nodes in a cluster tree network except leaf nodes, have to be coordinators. They usually work as cluster head and provide synchronization services in leaf nodes or other coordinators. These must also be FFDs.

Simple nodes: These are devices usually at the leaves of the networks. These devices perform the task of sensing or measuring, and of transmitting these measurements to the central entity. These can be RFDs.

LR- WPAN Specifications

The architecture for Low-Rate Wireless Personal Area Network comprises layers from both the IEEE 802.15.4 and ZigBee Alliance standardization bodies. The IEEE 802.15.4 standardization activity defines the lower two layers: the physical (PHY) layer and the medium access control (MAC) layer. The ZigBee Alliance builds on this foundation and provides the upper two layers: the network (NWK) layer and the application layer. Since in this work we consider only a simple star topology, with flow of traffic only from the leaf nodes to the hub, we need to consider only the PHY and MAC standards.

PHY Specifications

The PHY of an LR-WPAN is responsible for the following tasks:

- Activation and deactivation of the radio transceiver
- Channel frequency selection
- ED (energy detection) within the current channel
- Data transmission and reception
- LQI (link quality indication) for the received packets

MAC Specification

The MAC sublayer handles the following tasks:

- Generating network beacons if the device is a coordinator.
- Synchronization to the beacons.
- Supporting PAN association and disassociation.
- Supporting device security.
- Employing the CSMA-CA mechanism for channel access.
- Handling and maintaining the GTS mechanism.

3. THE CSMA-CA ALGORITHM

CSMA-CA algorithm is implemented using units of time, called backoff periods, each of length *aUnitBackoffPeriod* (= 20 symbol times). In slotted CSMA-CA, the backoff period boundaries of every device in the PAN shall be aligned with the superframe slot boundaries of the PAN coordinator and the MAC shall ensure that the PHY commences all of its transmissions on the boundary of a backoff period.

Each device shall maintain three variables for each transmission attempt: NB, CW and BE. NB is the number of backoffs the algorithm had to do while attempting the current transmission. CW is the number of backoff periods, that need to be clear of channel activity before the transmission can commence. MAC ensures this by performing *clear channel assessment* (CCA) at the boundary of CW consecutive backoff periods[1]. CW is set to 2 before each transmission attempt. BE is the backoff exponent. In slotted systems with *macBattLifeExt* set to TRUE, this value is initialized to lesser of 2 and the value of *macMinBE.* In other cases it is initialized to *macMinBE.*

4. A FIXED POINT EQUATION

Let us tag a node and obtain its β. A CCA from the tagged node will fail if, it finds the channel either in second CCA, T_{data-} or T_{coll} (see Figure 4.3). Let α_{CCA2}, $\alpha_{data\text{-}ack}$ and α_{coll} be the probabilities of the channel being in second CCA, $T_{data\text{-}ack}$ or T_{coll} respectively. These durations can be considered as "rewards" associated with various cycles of channel activity. Then, using the analysis in Section 4.1 and Appendix A the above probabilities can be given as:

$$\alpha_{CCA2} = \frac{\sum_{k=1}^{n-1} \pi_k E_k R^{CCA2}}{\sum_{k=1}^{n} \pi_k E_k U} =: H_{CCA2}(n-1,\beta)$$

$$\alpha_{data-ack} = \frac{\sum_{k=1}^{n-1} \pi_k E_k R^{data-ack}}{\sum_{k=1}^{n} \pi_k E_k U} =: H_{data-ack}(n-1,\beta)$$

$$\alpha_{coll} = \frac{\sum_{k=1}^{n-1} \pi_k E_k R^{coll}}{\sum_{k=1}^{n} \pi_k E_k U} =: H_{coll}(n-1,\beta)$$

Note that the right hand sides of the above three equations depend on β. Hence α, the probability that a tagged node's CCA will fail can be given in terms of β as

$$\alpha = H(n-1,\beta)$$

where,

$$H(\beta) = \alpha_{\text{CCA2}} + \alpha_{\text{data-ack}} + \alpha_{\text{coll}}$$

with each term being given by the equations above.

Also let $\alpha_{data\text{-}ack*}$ and α_{tack*} be the fractions of time, the channel is in $T_{data\text{-}ack*}$ and t_{ack*} respectively. These quantities can also be calculated as functions of β, in the way shown above. Let

$$\alpha_{\text{data-ack*}} = H_{data-ack*}(n-1,\beta)$$

and,

$$\alpha t_{ack*} = Ht_{ack*}(n-1,\beta)$$

$$H_{data-ack*}(n-1,\beta) := \frac{\sum_{k=1}^{n-1} \pi_k E_k R^{(data-ack*)}}{\sum_{k=1}^{n} \pi_k E_k U}$$

$$Ht_{ack*}(n-1,\beta) := \frac{\sum_{k=1}^{n-1} \pi_k E_k R^{(t_{ack*})}}{\sum_{k=1}^{n} \pi_k E_k U}$$

Evidently

$$\alpha_{data-ack} = \alpha_{data-ack*} + \alpha_{t_{ack*}}$$

Having obtained certain channel probabilities in terms of β, we now turn to obtaining β in terms of the channel probabilities, thus leading to a fixed point equation.

5.CALCULATION OF PERFORMANCE MEASURES

Throughput Calculation

To calculate the throughput, we again involve the Markov renewal process formulated earlier in Section 4.1. Successfully
sent data in a cycle can be considered as yet another "reward" associated with that cycle.
A successful data transmission will take place in cycle i only if (U_i X_i) = ($T_{data\text{-}ack}$ + 2δ , n - 1). Consider L_{data} as the size of a packet. Then, expected amount of data sent in a cycle, having *k* nodes to attempt at its beginning,,Hence the expected amount of data sent in a cycle, will be given by

$$E(L) = \sum_{k=1}^{n} \pi_k E_k L$$

Now, using the renewal reward theorem, the aggregate throughput *(8(n))* of the system with *n* sensor nodes can be seen to be:

$$\theta(n,\beta) = \frac{\sum_{k=1}^{n} \pi_k E_k L}{\sum_{k=1}^{n} \pi_k E_k U}$$

6. NUMERICAL RESULTS

The analytical as well as simulation results for the case when only one backoff failure for a packet is admitted and default backoff parameters are used.Both analyses are able to capture the trends of all the performance measures quite well in all the cases.

7. CONCLUSION

In this work we give a brief description of LR-WPAN standard and also cite various uses of these networks. We then provide an approximate fixed point analysis for a saturated star network with nodes uniformly distributed, and equidistant for the PAN coordinator.

8. REFERENCES

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