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Research Article

Analysis and simulation of Network Inaccessibility in LR-WPAN using NS2

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Abstract

Wireless technology has many challenges for predictability and time-bounded communications over the temporary partition, called inaccessibility. Network inaccessibility is a temporal issue derived by the Medium Access Control sublayer in presence of fault affecting the communication services. Reducing the network inaccessibility in IEEE 802.15.4 wireless communications is most challenging step to enhance network communication in terms of dependability, timeliness and predictability, which enforce real-time operation. In beacon-enabled and non-beacon enabled mode, link failure self- recovery, low duty cycle, association to shape up the entire network to work efficiently has been analysed. Simulation result shows the network performance in terms of Quality of Service metrics, association, orphaning and recovery for different topologies.

Keywords: *Low Rate-Wireless Personal Area Network (LR-WPAN), Quality of Service (QoS), MAC*

1. Introduction

The typical scenario of an LR-WPAN is a densely distributed unattended wireless sensor network. Such network needs highly self-configuration feature in deployment and auto-recovery from failure. IEEE 802.15.4 (IEEE standard 802.15.4 2008) works in two operational mode: beacon-enabled and non-beacon enabled, designed to support traffic with temporal restrictions. Its success lies in the design of a very straightforward protocol stack comprising the physical (PHY) and medium access control (MAC) layers, both developed for low-cost, low-power and resource-constrained wireless devices. The goal of this standard is to provide an appropriate solution for a few devices/nodes deployed in a small-sized area. Devices acquire data of interest (monitoring one or several physical parameters) and transmit them to their destination (sink) periodically or in event-driven fashion.

Disturbance induced in the functioning of medium access control (MAC) protocol may create temporary partitioning in the network. These disturbances can be produced by external interference or by some glitches in the functioning of MAC sub-layer. A solution for controlling network inaccessibility is to maintain an effective and efficient real time wireless communication. IEEE 802.15.4 uses two types of devices: full function devices (FFD) and reduced function device (RFD) which works in three different topologies namely star, peer-to-peer and cluster-tree. FFD is a full function device that can be a PAN-coordinator, a coordinator, or just an end device and RFD is a reduced functionality device that acts as an end device only. In an established network, PAN coordinator provides a synchronization services. The default superframe structure is used by coordinator for accessing. In star topology PAN coordinator is placed at the centre of the simulation area it is the main powered device and does not requires any battery. The sink node is FDD which collects all information from various nodes. Meanwhile all the other nodes will act as end devices.

The rest of this paper has been organized in following sections: Section 2, briefly discuss the related work. In section 3, inaccessibility in IEEE 802.15.4 has been analysed. Section 4, provides experimental set-up and simulation parameters and section 5 gives the results and discussion, and this paper has been concluded in section 6.

2. Related Work

A variety of configuration that uses to detect and reduce inaccessibility in IEEE 802.15.4 network has been taken into account. Most of the research on WSNs has been done for designing of energy efficient algorithm & protocols.

Aad *et al.* proposed a mechanism, called elastic MAC (E-MAC) protocol to overcome the lack of strict

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QoS guarantees in existing hotspots, with a system for real-time traffic support in 802.11 networks that works in either infrastructure or ad-hoc mode. Kuhn *et al.* proved that a diversity of possible communication assumptions complicates the study of algorithms and lower bounds for radio networks by addressing this problem by defining an Abstract MAC Layer. Sahoo *et al.* presented RTMAC, a real-time MAC protocol based on TDMA protocol for wireless sensor network to provide delay guarantee and to overcome the high latency of traditional TDMA. Souza *et al.* proposed a module to measure and validate the occurrence of network inaccessibility in an IEEE 802.15.4. Garg *et al.* presented the impact of beacon order mode with different on demand routing protocols. Latre *et al.* analysed throughput, delay and bandwidth efficiency for different scenarios in LR-PAN under beaconless mode. The authors of analyzed the performance of IEEE 802.15.4 MAC, by using node state and channel state models, and presented an analytical model for the slotted CSMA/CA algorithm adopted in the CAP of the beacon-enabled mode, which only considers for saturated mode but not for acknowledgement (ACK). In [16], authors presented an evaluation of slotted CSMA/CA of IEEE 802.15.4 based on all of its frequency, which analyses each frequency and compares with each other. Chen *et al*. analyzed the performance of beacon-enabled IEEE 802.15.4 for industrial application in star network. Chen F et al, (2010) modified IEEE 802.15.4 protocol for real-time applications in industrial automation, after analyzing the simulation environment. Zen *et al.* analyzed the performance of IEEE 802.15.4 by evaluating the suitable protocol in mobile sensor network. Mehta *et al.* proposed an analytical model to understand and characterize the performance of GTS traffic in IEEE 802.15.4 networks for emergency response.

3. Inaccessibility in IEEE 802.15.4

There are a number of causes for inaccessibility due to loss of node synchronization. Mobility changes the node's position causing the inaccessibility. Electromagnetic interference, disturbance in node receiver circuitry, hidden and exposed terminal collision, glitches in PAN coordinator or even its failure leads to inaccessibility. To achieve the support of real-time communication over wireless networks, knowledge of inaccessibility time bounds is important. Based on the information, auto reconfiguration and self-healing management entities, node may take the appropriate recovery action. Beacon-enabled PAN use a superframe structure as shown in fig.1.

This structure is time bounded by periodic transmissions of beacon frames with the periodicity of beacon interval (BI), determines the actual time interval between the consecutive beacon frames, considering the minimum superframe duration and beacon order. And active portion of superframe structure's duration consists of CAP and CFP together is given by $T_{BSD}.2^{SO}$, if BO=SO, within the superframe, no inactive period (IP) is present.

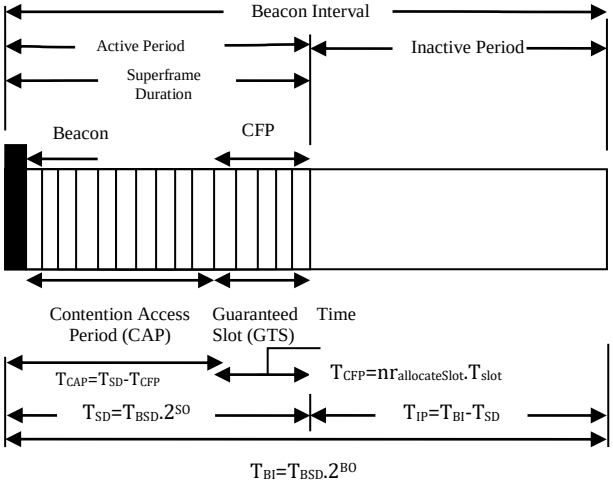

Fig.1 Superframe Structure in Beacon-enabled mode

The real T_{BI} is used to normalize duration of network inaccessibility events. Disruption and unpredictability in network operation are validated through long and highly variable periods of network inaccessibility.

3.1 Synchronization Loss

In beacon-enabled mode, a device tracks the beacon to synchronize with the coordinator for data polling, energy saving, and orphaning detection. To synchronize within different periods of superframe structure, the beacon frame controls the access to the network. Network inaccessibility occurs in case of incorrect reception of beacon frame. When multiple beacon frames are lost, a node loses synchronization with the network coordinator. The synchronization loss within a network is given by

$$T_{ina\leftarrow nosync} = nrLost.(T_{BSD}.(2^{BO}+1))$$

Where, a node searches for beacon frames during at most $T_{BSD}.(2^{BO}+1)$ times, i.e., wait period of at most $T_{BSD}.(2^{BO}+1)$ symbols.

3.2 Orphaning

Orphaning is related to the association as it works only if a device keeps tracking the beacons, and is successfully associated with the beaconing coordinator. During last beacon interval, if data/control frame is received, node assumes to be in orphan state, otherwise re-association procedure is carried out. If the node is orphaned, a request is issued to the MAC layer to start an orphan scan recovery action, over a specified set of logical channels. Orphaning includes the number of channel scanned, waiting period for a beacon frame in each scan, delay in request confirming MAC frame transmission with and without acknowledgement. Once MAC command is received the node terminates the scan and acknowledges the frame reception and the network become accessible.

$$T_{ina\leftarrow orphan} = T_{ina\leftarrow nosync} + T_{HLP}(orphan) + \sum_{i=1}^{nrchannels}\{T_{MAC}(orphan) + nrWait.T_{BSD}\} + T_{ackDelay} + T_{ack}$$

Where, T_{HLP} is the time taken in high layer protocol management actions. If orphan realignment succeeded at the first attempt, the inaccessibility period is given by the equation

$$T_{ina\leftarrow orphan} = T_{ina\leftarrow nosync} + T_{HLP}(orphan) + T_{MAC}(orphan) + T_{HLP}(Realign) + T_{MAC_{ack}}(Realign)$$

3.3 Relocation

802.15.4 includes association and dissociation mechanism together with orphaning and relocation mechanism for the coordinators. A node sends a beacon request and waits for reception of it. With the successful beacon reception, recovery proceeds with an association and the extraction of control information from the network coordinator. Relocation provides a chance to self-configuration because of disruption.

3.4 GTS Allocation

While working in beacon-enabled mode, a coordinator can allocate device's active superframe known as GTSs, comprises the superframe's contention free period (CFP). In default superframe structure, during CAP and CFP, nodes compete in equal condition to access the network in non-real time and within the exclusive time slots (GTS) supporting real-time traffic respectively. In GTS data transmission, traffic uses the time division multiple access (TDMA) approaches and optional inactive period, to enter power save mode. GTS allocation is extremely important for bandwidth reservation. No CSMA/CA (Vinamrata et al, 2016)is needed in GTS data transmission. The allocation of GTS is performed sending a MAC GTS request command to the associated coordinator, which should be acknowledged. In case of inaccessibility, node does not receive this acknowledgment.

$$T_{ina\leftarrow GTS} = T_{MAC_{ack}}(GTS)$$

3.5 Association Efficiency

A device performs channel scanning, to associate with the coordinator. Active channel scan sends a beacon request frame while in passive scan, no beacon frame is sent, to locate a suitable coordinator. In case of active scanning for beacon-enabled mode, coordinator discards the frame silently, due to periodic sending of beacons while coordinator needs to unicast a beacon to the device soliciting beacons.

4. Simulation Parameters

The simulations has been done using NS-2 (http:/www.isi.edu/nsnam/ns) and carry out several set of experiments to evaluate the performance of TDMA–MAC in star and cluster tree topology and beacon enabled IEEE 802.15.4 MAC using CSMA/CA in star and cluster tree topology. In multi-hop network, association is based on tree formation, as the efficiency of tree formation is directly related to the association efficiency. For routing purpose, tree is a better structure and can be used by network layer.

Table 1 Simulation parameters

Parameter	Values
Simulation area	50x50
Number of nodes	40
Traffic type	CBR
nrWait	32
nrLost	4
macBeaconOrder (BO)	0-15
aNumSuperframeSlots	16

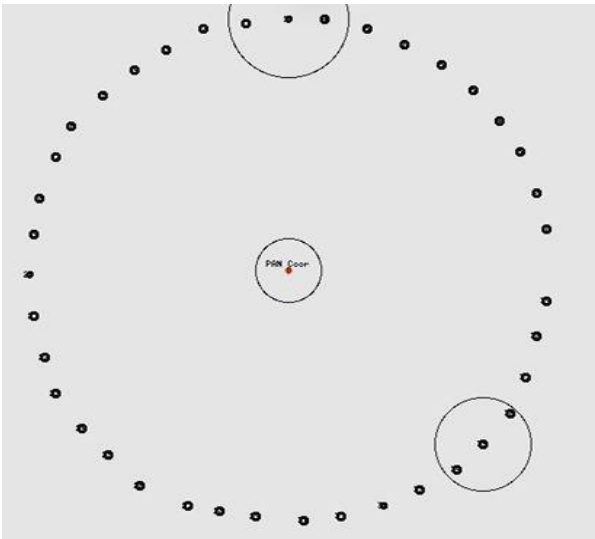

Fig. 2 Experiment Scenario for Star topology

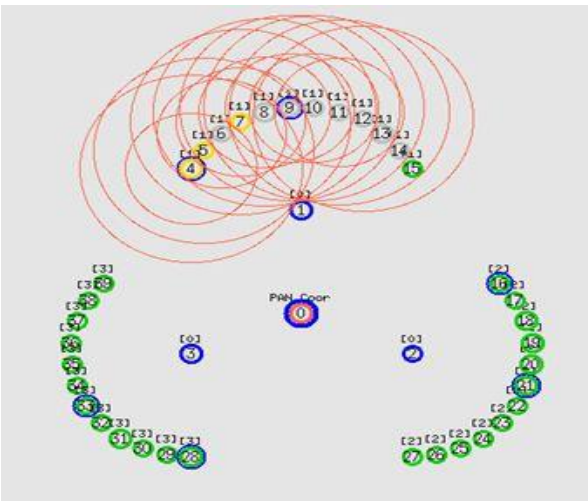

Fig. 3 Experiment Scenario for Cluster-tree topology

For star topology, 40 nodes has been placed, one is taken as PAN Co-ordinator that synchronises the rest 39 end devices, placed in circular manner. For cluster

tree scenario one PAN Co-ordinator, 3 co-ordinator and 36 end devices has been taken. PAN Co-ordinator synchronises the co-ordinate and then the co-ordinate synchronises the respective devices.

5. Result and Discussion

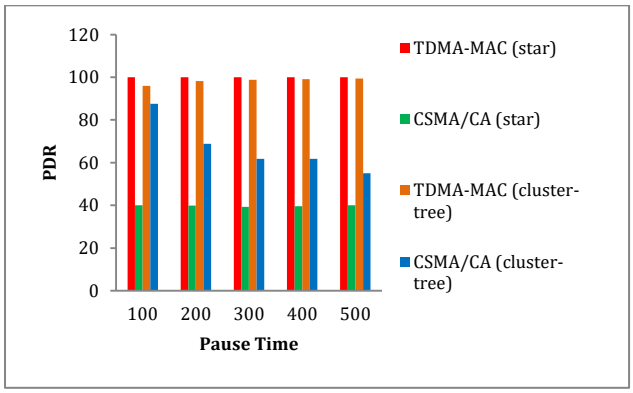

Fig. 4 PDR Vs Time

Fig. 4 gives the packet delivery ratio with pause time. It defines the packets successfully received to the packets sent in MAC sublayer. It includes both transmitted and retransmitted packets.

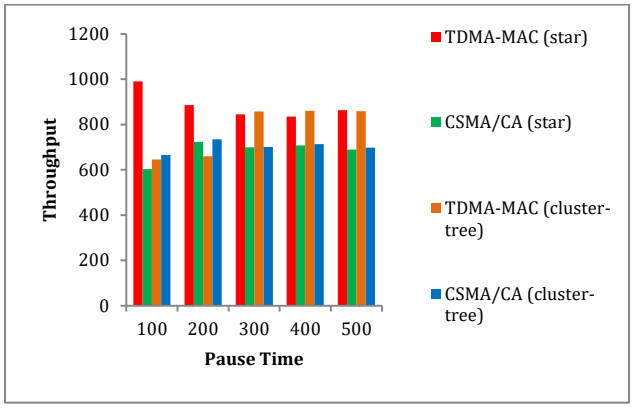

Fig. 5 Throughput Vs Pause Time

Fig. 5 shows the throughput with the pause time.

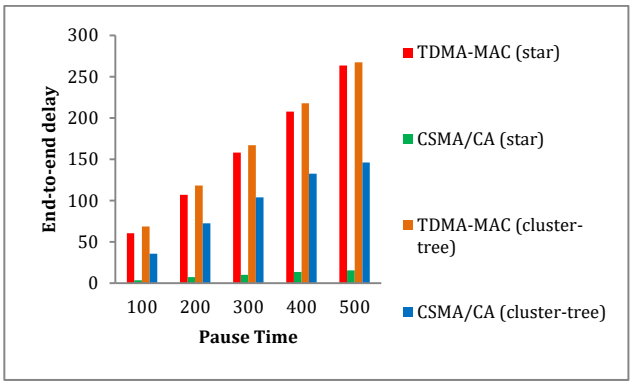

Fig. 6 End-to-end Delay Vs Pause Time

Fig. 6 shows end-to-end delay for different topologies. CSMA/CA in star topology has least end-to-end delay.

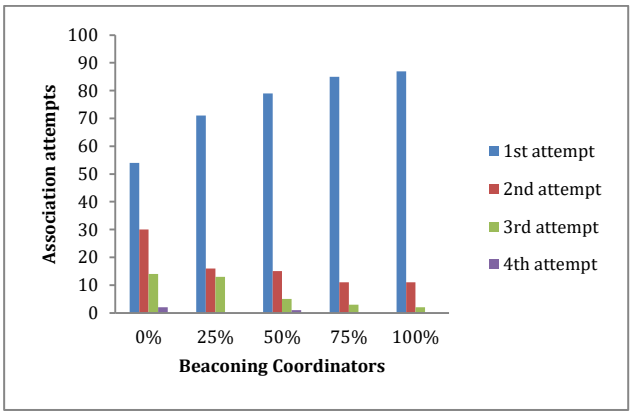

Fig. 7 Association attempts Vs Beaconing Coordinators

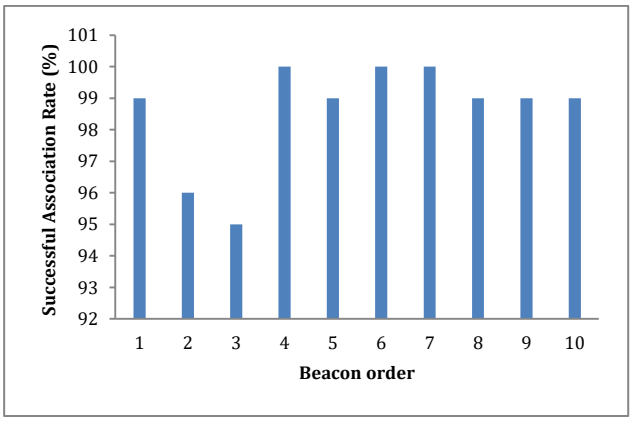

Fig. 8 Successful Association Rate (%) Vs Beacon Order

Fig. 7 and fig. 8 shows the association efficiency. Fig. 7 gives the average number of attempts per successful association. A device gets an almost equal chance to associate with a beaconing coordinator or a non-beaconing coordinator. While fig. 8 gives the successful association rate for different beacon orders, which shows the performance of larger beacon order is better than that of smaller one.

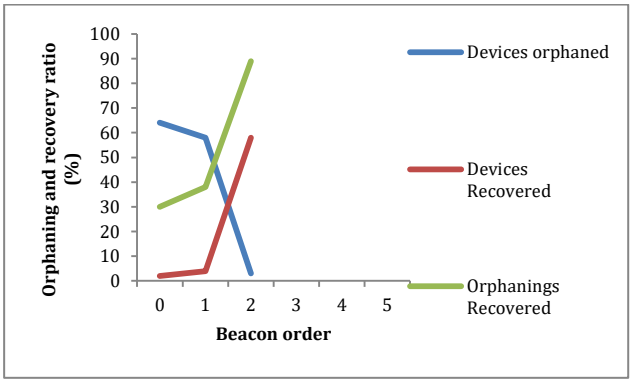

Fig. 9 Orphaning and recovery ratio Vs Beacon order

Fig. 9 shows the device orphaned, device recovered and orphaning recovered with the beacon order. A

device is considered to be orphaned if it misses consecutive *aMaxLostBeacons* (default value 4) beacons from the coordinator. There is no orphaning in beacon order 3 or more.

Conclusion

The control of hidden MAC sublayer, which makes support of real-time communication in lower level protocols, omits the failure considering various inaccessibility parameters. The orphaning and coordinator relocation mechanism provides a chance of self-healing from disruption. The analytical model shows the beacon-enabled PAN to control medium access, for reliable and real-time communication.

Future research work can assess new techniques using multiple communication channels, message scheduling and analyzing delays to provide support to scenario under consideration for efficient communication.

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