ANALYSIS OF THROUGHPUT USING GTS AND MULTI-CHANNEL IN IEEE 802.15.4

First A. Abhinav Singh [1]; Second B. Pankaj Kumar Patel [2]; Third C. Dr.P.C.Jain [3];
Centre for Development of Advanced Computing, Noida, India

Abstract

The current IEEE 802.15.4 standard restricts the beacon enabled approach to star networks, while they support multi-hop networking in mesh but with no synchronization. In this paper there is proposal of a multichannel to overcome GTS limitations and improve GTS usability in cluster networks.

Introduction

The IEEE 802.15.4 [1] MAC protocol supports two operational modes: the beaconless mode, in which nodes stay active all the time, and the beacon mode, in which beacon frames are periodically sent by coordinators to synchronize sensor nodes. The advantage of this synchronization scheme is that all nodes can wake up and sleep at the same time allowing very low duty cycles and hence save energy. In addition, when the beacon mode is used, nodes can use Guaranteed Time Slots specifically designed to fulfill application's QoS requirements but due to beacon frame collision beacon mode is limited. Beacon frame collision can be avoided if different channels are used for transmission in cluster tree network. The cluster tree network is a special case of a peer- to-peer network in which most devices are FFDs. Any of the FFDs may act as a coordinator and provide synchronization services to other devices or other coordinators. Only one of these coordinators can be the overall PAN coordinator.

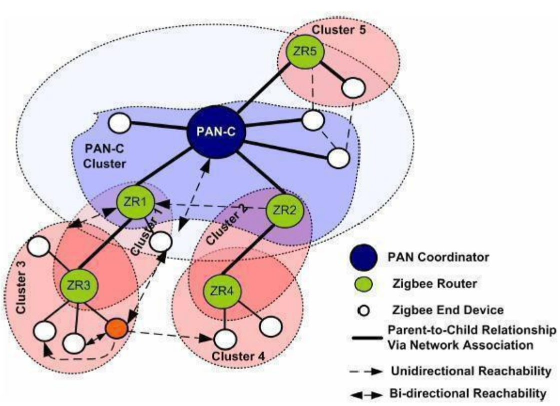


Figure 1 Cluster Tree Network

Beacon Frame collision

The Task Group 15.4b has identified two types of collisions:

i) Direct beacon frame collisions
ii) Indirect beacon frame collisions

Direct beacon frame collisions [2] occur when two or more coordinators are in the transmission range of each other and send their beacon frames at approximately the same time. Assuming that node N1 is a child of ZR1, which sends its beacon frame at approximately the same time as ZR2, node N1 loses its synchronization with its parent ZR1 due to the collision of beacon frames from ZR1 and ZR2.

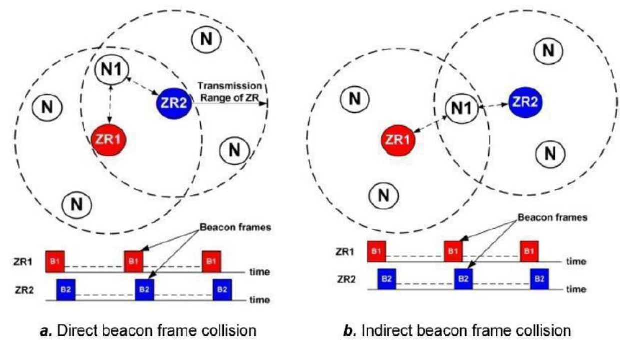


Figure 2 Beacon Frame Collision

Indirect beacon frame collisions occur when two or more coordinators cannot hear each other, but have overlapped transmission ranges and send their beacon frames at approx. the same time. Note that collisions between data and beacon frames may also happen.

To avoid beacon frame collision the two common approaches are SDS and BOP approach. SDS approach leads to more and more delay as number of nodes increases and BOP approach needs modification of superframe structure. In this paper we propose a Multichannel approach to avoid beacon frame collision and to increase the GTS.

Multichannel Approach

Current GTS is only for the connection between device and coordinator. But GTS can be applied for the communication from device to device. GTS communication through multi-channel may be used to improve the throughput capacity in WPAN.

TG4e [3] has provided an approach where data can be transferred using GTS between devices in mesh. In our proposed approach we extend this approach to chain topology a special case of cluster tree network.

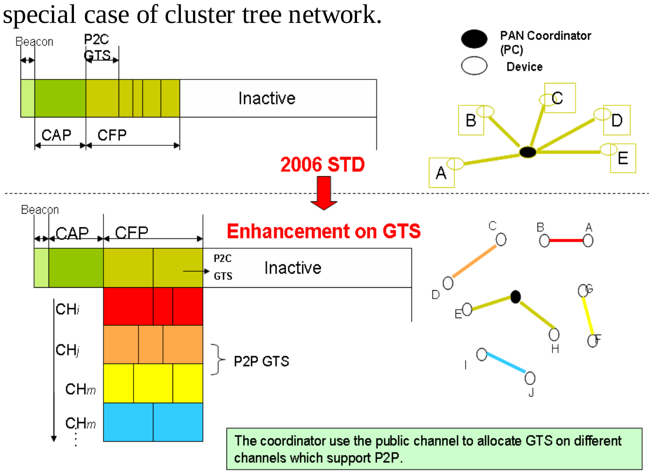


Figure 3 Multichannel for mesh topology

Figure 3 communication in two parts, the first part separated by line shows communication through GTS in star network between device to coordinator and second part shows the communication between devices in mesh topology.

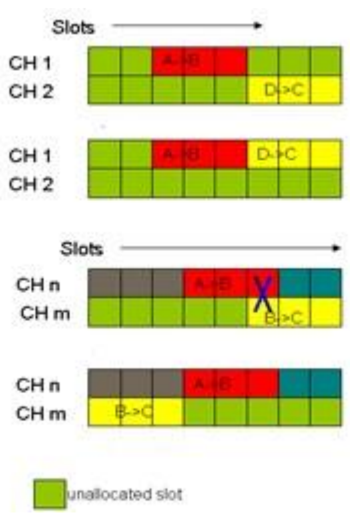


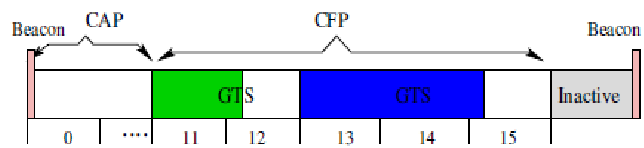
Figure 4 Valid GTS allocation

The PAN coordinator first considers allocating a new GTS on the channel with allocated GTSs if enough capacity is there, otherwise, other suitable channels will be selected. If there are several P2P GTSs related with one node (node B), the PAN coordinator shall guarantee that there is no overlay slots between any two P2P GTSs aMinCAPperiod should be maintained when allocating GTS.

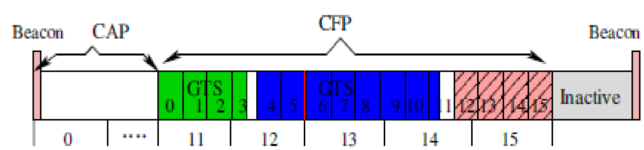
Granulated GTS allocation scheme

When the traffic rate is less than the available bandwidth, a portion of the GTS will be idle. This becomes an unused hole [4] in the CFP. The sum of the total unused holes can satisfy a GTS needed by another node, but none of them alone is long enough. Thus, a portion of the CFP is wasted. The CFP can be divided into much smaller slot.

In Figure 5 the colored areas indicate the GTS usage. In the standard GTS allocation scheme shown, the first GTS consists of slot 11, and slot 12; the second GTS consists of slot13, 14 and 15.However, they are not fully utilized. In the new GTS allocation scheme, the CFP is divided into 16 equally sized time slots.



(a) the standard GTS allocation and their usage



(b) Proposed method of GTS allocation and their usage

Figure 5 GTS Allocation and their usage

The first GTS consists of slot 0, 1, 2, and 3. The (starting Slot, length) pair in its GTS descriptor is (0000, 0100) b. The second GTS consists of slot 4, 5, 6, 7, 8, 9, 10, 11. And the (starting Slot, length) pair is (0100, 1000) b in its GTS descriptor. The remainder of the CFP, slots 12, 13, 14 and15, can satisfy the need of another device with a comparable traffic generating rate of the first device.

Proposal of Multi-channel Approach in Chain Topology

Chain topology is a special case of cluster tree network. All the nodes are connected in a chain fashion. In the Fig.6 ten nodes are shown connected in chain topology. PNC is marked as P and shown in red color. All the nodes except the last node marked as A are FFD. Node marked as A is RFD. Data transmission is from node A to PNC through GTS.

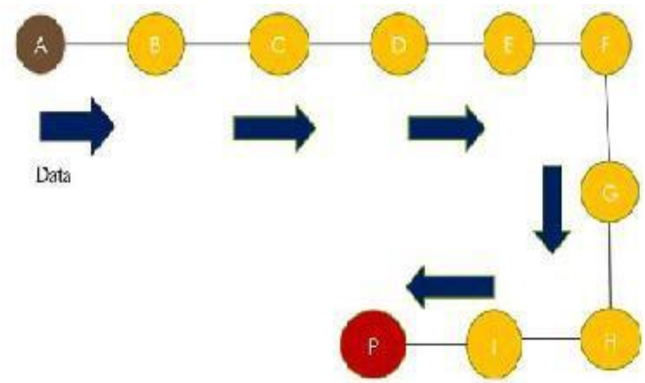


Figure 6 Chain topology showing data transfer from A to P

GTS characteristic and Beacon frame format are modified to have multiple channels for transmission.

A. GTS Characteristic field modification

GTS characteristic as in IEEE802.15.4 is shown with modified GTS characteristic in Fig.7. Two columns containing GTS mode and peer to peer destination address is added in the modified characteristic field.

Bit: 0 ~ 3	4	5	6 ~ 7
GTS Length	GTS Dir	Charc Type	Reserved

Bit: 0 ~ 3	4	5	6 ~ 7	8 ~ 23
GTS Length	GTS Dir	Charc Type	GTS Mode	P2P Destination Address

Figure 7 Modified GTS characteristic Field

If GTS mode is P2C, the field of P2P destination address is omitted and if GTS mode is P2P, the GTS Request command frame must be sent by P2P sponsor and the field of GTS Dir. must be set transmit-only.

B. Beacon Frame Format Modifications

In beacon frame there is extension of the reserved bit 3-6 of the GTS specification field to 'P2P GTS Descriptor Count' and addition of the P2P GTS descriptor field into the GTS list.

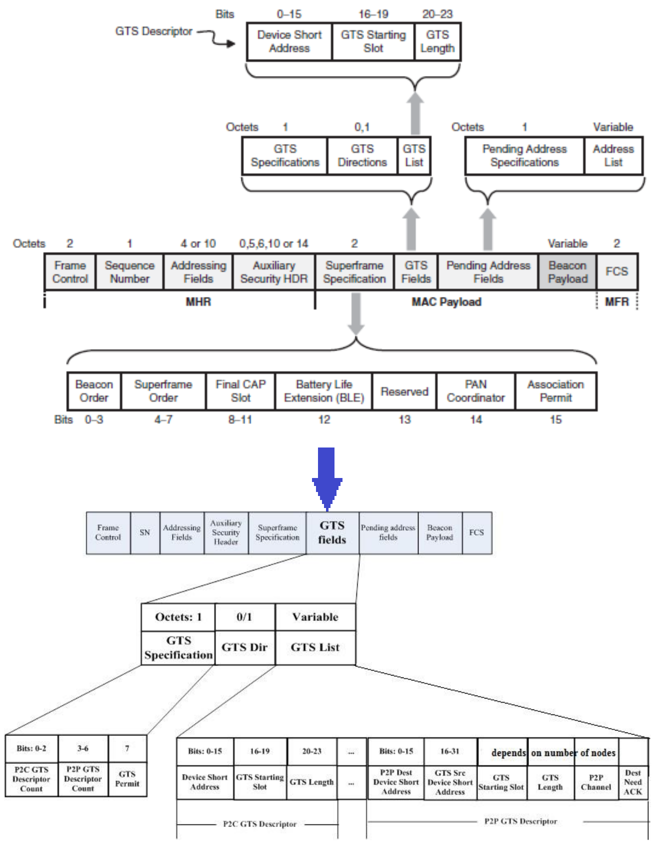


Figure 8 Modified Beacon Frame Format

No. of bits needed in P2P GTS descriptor depends on the number of intermediate nodes in chain network as every intermediate node with the source node has to be allotted a channel and slots available such that there is no overlay slots.

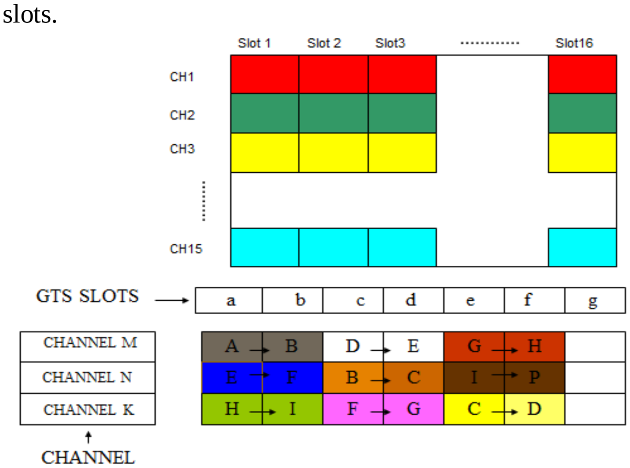


Figure 9 Data transmission through multichannel

In our proposal we divide the GTS of every node as shown in Fig.5, thus making 16 slots from 7 slots and then scheduling the GTS as shown in Fig.4. Using multichannels, throughput is observed. In our proposed scheme, we apply this concept to chain topology and apply it for 10 nodes as shown in Figure 6.

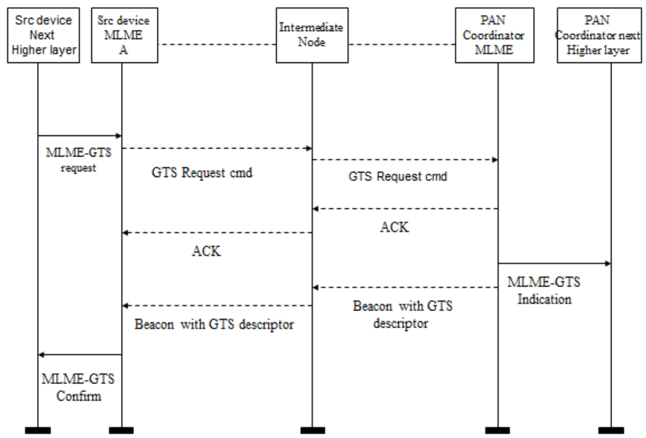


Figure 10 P2P Source device request P2P GTS allocation

The source device sends GTS request command frame to PAN coordinator through intermediate nodes. PAN Coordinator after receiving the request command responds with the ACK frame immediately. In the next superframe, the beacon frame with GTS descriptor is transmitted by PNC towards source device. GTS descriptor allocates the channel and the slots to the intermediate nodes and the source.

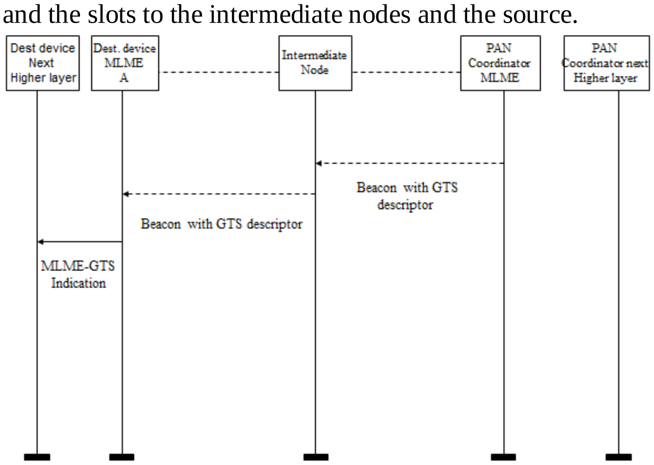


Figure 11 PNC notifies the destination

If destination is different from the PNC then PNC transmits the GTS descriptor towards destination through intermediate nodes. If PNC itself is destination then PNC identifies itself as the destination node like in in Figure 6.

Evaluation and Results

A node that has been [5] allocated a GTS can transmit a message if and only if the whole transaction, including data transmission, the Intra-Frame Spacing (IFS), can be completed before the end of the GTS. Otherwise, it must wait until the next GTS. Parameters defined in our proposal are given in Table 1.

Table1. Parameters

Parameters	Values
SIFS	48 bits
LIFS	160 bits
Beacon Frame Time	0.896 msec
Rx-Tx Turnaround Time	0.192 msec
aMaxPHYPacketSize	1016 bits
aUnitBackoff Period	0.320 msec
aBaseSuperframeDuration	15.36 msec
aMaxSIFS Framesize	144 bits
aMinCAPLength	7.04 msec
SO	3
BO	4

For our proposed scheme we took 5Kbps data rate and 10 Micaz nodes. SoC used for our proposal analysis is XbeePro with development kit CC2520, Iwise-msp430f2618 and TELOSB-msp430f1611.

Equations from network calculus are used for analytical results and throughput is calculated at each and every node. Throughputs at some of the nodes are given in Table 2.

Table2. Throughput at some nodes

Node	Throughput
2	3.47 Kbps
4	1.011 Kbps
6	0.219 Kbps
8	0.0477 Kbps
10	0.0103 Kbps

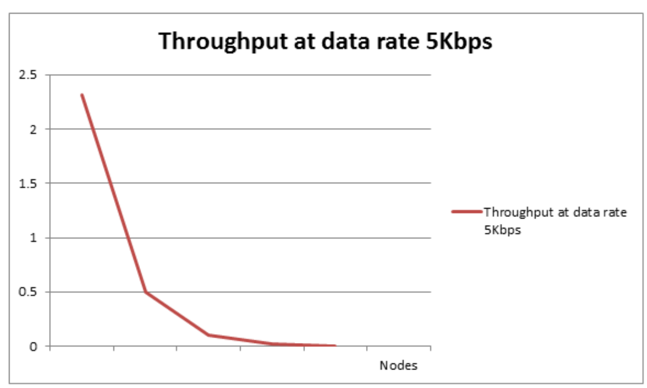


Figure 12 Throughput curve

As the number of nodes increases throughput of the network decreases and for very large network throughput becomes negligible. Calculation for throughput is done considering long frames and the neglecting time for GTS Request command and GTS descriptor.

Figure 12 shows the curve obtained for throughput through our proposed scheme for chain topology. Throughput de- creases with different slopes as number of nodes increases and if the numbers of nodes are high then throughput achievable is very low.

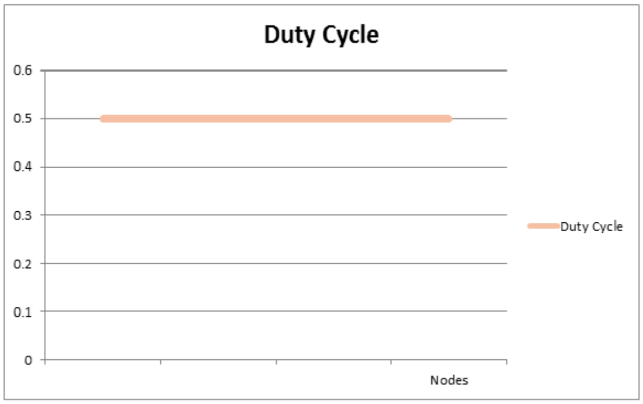


Figure 13 Duty Cycle Graph

Duty cycle remains constant throughout the chain network with a constant value of 0.5.

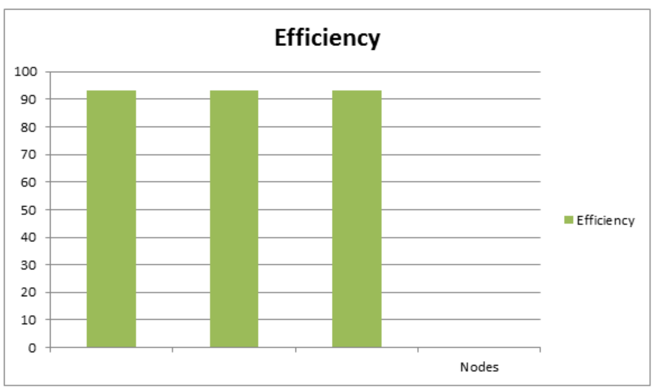


Figure 14 Efficiency Bar

Efficiency remains constant in our proposed scheme for chain topology network as shown in Fig.14.

Conclusion

The scheme proposed in this approach provides a convenient way to use GTS in multihop. It also removes the limitations of GTS but shows that a very low throughput is achieved when GTS is used in large chain network.

Acknowledgments

We are thankful to research and development embedded division of CDAC Noida for providing the support and environment to develop the proposed scheme in this paper.

References

[1] IEEE 802.15.4 Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs), 2006

[2] A.Koubâa, A. Cunha, M. Alves, E. Tovar,"TDBS: a time division beacon scheduling mechanism for Zigbee cluster-tree wireless sensor networks", Real- Time Systems, 40, 3(Dec.2008), pp. 321-354

[3] Jie Shen , Daoyuan Yao, Tao Xing, Z.F Zhao, Haitao Liu," Supporting Peer to Peer Network and Improving throughput by enhanced GTS", in the IEEE 802.15.4 T G 4e,September 2008.

[4] L. Cheng, A. G. Bourgeois, and X. Zhang, A new GTS allocation scheme for IEEE 802.15.4 net-works with improved bandwidth utilization to appear in 7th International Symposium on Communications and In- formation Technologies (ISCIT), Oct 2007.

[5] Anis KOUBAA, Mário ALVES, Eduardo TOVAR, "GTS Allocation Analysis in IEEE 802.15.4 for Real- Time Wireless Sensor Networks". 20th International Conference on Parallel and Distributed Processing Symposium, pp. 8, April 2006.