Cluster based designing of ZigBee protocol using MATLAB

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***Abstract* -** This paper is organized the proposed general methodologies are applied to the specific case of IEEE 802.15.4/ZigBee beacon-enabled cluster-tree WSNs. an overview to the most significant features of the IEEE 802.15.4 standard and ZigBee specification , which are the leading communication technologies for flow data rate, flow cost and flow power consumption WSNs. an accurate IEEE 802.15.4/ZigBee simulation model and provides a novel methodology to tune the IEEE 802.15.4 parameters such that a better performance can be guaranteed. Assuming a static cluster-tree WSN with a set of multi-source mono-sink time-bounded data flows *Index.*

***Keywords* -** IEEE 802.15.4/ZigBee, beacon, ZigBee

I. INTRODUCTION

IEEE 802.15.4 [1] standard and ZigBee [2] specification stand as the leading communication technologies for large scale, low data rate, low cost and low power consumption Wireless Sensor Networks (WSNs) (In 2012, 802.15.4-enabled chips will reach 292 million, up from 7 million in 2007 [3]). IEEE 802.15.4/ZigBee is quite flexible for a wide range of applications by adequately tuning their parameters. They can also provide real-time guarantees for time-sensitive WSN applications. Sometimes, people confuse IEEE 802.15.4 with ZigBee. The IEEE 802.15.4 standard specifies the physical layer and medium access control (MAC) sub-layer, while the network layer and the framework for the application layer are provided by the ZigBee specification such that a full protocol stack is defined. Recently the ZigBee Alliance and the IEEE decided to join forces and ZigBee is the commercial name for the IEEE 802.15.4/ZigBee communication technology.

The IEEE 802.15.4 standard defines two main types of wireless nodes: a Full-Function Device (FFD) and a Reduced-Function Device (RDF). The FFD implements all the functionalities of the 802.15.4 protocol and can operate in three modes serving as a PAN (Personal Area Network) coordinator, a coordinator, or an end device. ZigBee protocols are intended for use in embedded applications requiring low data rates and low power consumption. ZigBee's current focus is to define a general-purpose, inexpensive, self-organizing mesh network that can be used for industrial control, embedded sensing, medical data collection, smoke and intruder warning, building automation, home automation, etc. The resulting network will use very small amounts of power individual devices must have a battery life of at least two years to pass ZigBee certification There are three different types of ZigBee devices:

- ZigBee coordinator (ZC): The most capable device, the coordinator forms the root of the network tree and might bridge to other networks. There is exactly one ZigBee coordinator in each network since it is the device that started the network originally. It is able to store information about the network, including acting as the Trust Centre & repository for security keys.
- ZigBee Router (ZR): As well as running an application function a router can act as an intermediate router, passing data from other devices.
- ZigBee End Device (ZED): Contains just enough functionality to talk to the parent node (either the coordinator or a router); it cannot relay data from other devices. This relationship allows the node to be asleep a significant amount of the time thereby giving long battery life. A ZED requires the least amount of memory, and therefore can be less expensive to manufacture than a ZR or ZC.

II. ZIGBEE PROTOCOLS

The protocols build on recent algorithmic research (Ad-hoc On-demand Distance Vector, neuRFon) to automatically construct a low-speed ad-hoc network of nodes. In most large network instances, the network will be a cluster of clusters. It can also form a mesh or a single cluster. The current profiles derived from the ZigBee protocols support beacon and non-beacon enabled networks[3].

In this type of network, ZigBee Routers typically have their receivers continuously active, requiring a more robust power supply. However, this allows for heterogeneous networks in which some devices receive continuously, while others only transmit when an external stimulus is detected. The typical example of a heterogeneous network is a wireless light switch: the ZigBee node at the lamp may receive constantly, since it is connected to the mains supply, while a battery-powered light switch would remain asleep until the switch is thrown. The switch then wakes up, sends a command to the lamp, receives an acknowledgment, and returns to sleep. In such a network the lamp node will be at least a ZigBee Router, if not the ZigBee

Coordinator; the switch node is typically a ZigBee End Device [4].

In beacon-enabled networks, the special network nodes called ZigBee Routers transmit periodic beacons to confirm their presence to other network nodes. Nodes may sleep between beacons, thus lowering their duty cycle and extending their battery life. Beacon intervals may range from 15.36 milliseconds to 15.36 ms * 2^{14} = 251.65824 seconds at 250 kbit/s, from 24 milliseconds to 24 ms * 2^{14} = 393.216 seconds at 40 kbit/s and from 48 milliseconds to 48 ms * 2^{14} = 786.432 seconds at 20 kbit/s. However, low duty cycle operation with long beacon intervals requires precise timing, which can conflict with the need for low product cost. In general, the ZigBee protocols minimize the time the radio is on so as to reduce power use. In beaconing networks, nodes only need to be active while a beacon is being transmitted. In non-beacon-enabled networks, power consumption is decidedly asymmetrical: some devices are always active, while others spend most of their time sleeping. ZigBee devices are required to conform to the IEEE 802.15.4-2003 Low-Rate Wireless Personal Area Network (WPAN) standard. The standard specifies the lower protocol layers—the physical layer (PHY), and the medium access control (MAC) portion of the data link layer (DLL). This standard specifies operation in the unlicensed 2.4 GHz, 915 MHz and 868 MHz ISM bands. In the 2.4 GHz band there are 16 ZigBee channels, with each channel requiring 5 MHz of bandwidth. The center frequency for each channel can be calculated as, F_C = (2405 + 5 * (ch - 11)) MHz, where ch = 11, 12... 26.

The software is designed to be easy to develop on small, inexpensive microprocessors. The radio design used by ZigBee has been carefully optimized for low cost in large scale production. It has few analog stages and uses digital circuits wherever possible. Even though the radios themselves are inexpensive, the ZigBee Qualification Process involves a full validation of the requirements of the physical layer. This amount of concern about the Physical Layer has multiple benefits, since all radios derived from that semiconductor mask set would enjoy the same RF characteristics. On the other hand, an uncertified physical layer that malfunctions could cripple the battery lifespan of other devices on a ZigBee network. Where other protocols can mask poor sensitivity or other esoteric problems in a fade compensation response, ZigBee radios have very tight engineering constraints: they are both power and bandwidth constrained. Thus, radios are tested to the ISO 17025 standard with guidance given by Clause 6 of the 802.15.4-2006 Standard. Most vendors plan to integrate the radio and microcontroller onto a single chip.

An academic research group has examined the ZigBee address formation algorithm in the 2006 specification, and argues[6] that the network will isolate many units that could be connected. The group proposed an alternative algorithm with similar complexity in time and space. A white paper published by a European manufacturing group (associated with the development of a competing standard, Z-Wave) claims that wireless technologies such as ZigBee, which operate in the 2.4 GHz RF band, are subject to significant interference - enough to make them unusable[7]. It claims that this is due to the presence of other wireless technologies like Wireless LAN in the same RF band. The ZigBee Alliance released a white paper refuting these claims[8]. After a technical analysis, this paper concludes that ZigBee devices continue to communicate effectively and robustly even in the presence of large amounts of interference.

Claim that the term “ZigBee” originates from the zig-zag waggle dance honeybees use to share critical information, such as the location, distance, and direction of a newly discovered food source, with fellow hive members. ZigBee device manufacturer Meshnetics refers to this communication system as the “ZigBee Principle[7]. However, no such term exists in apology, the scientific study of honeybees. Robert Metcalfe, inventor of Ethernet and a worker on the initial development on ZigBee, confirmed to a journalist in 2004 that the name was initially meaningless and had been chosen from a long list on the basis that it had no trademark liabilities

III. REQUIREMENT OF ZIGBEE

ZigBee’s protocol code stack is estimated to be about 1/4th of Bluetooth’s or 802.11’s. Simplicity is essential to cost, interoperability, and maintenance. The IEEE 802.15.4 PHY adopted by ZigBee has been designed for the 868 MHz band in Europe, the 915 MHz band in N America, Australia and the 2.4 GHz band is now recognized to be a global band accepted in almost all countries.

A. *ZigBee/IEEE 802.15.4 - General Characteristics*

- Dual PHY (2.4GHz and 868/915 MHz)
- Data rates of 250 kbps (@2.4 GHz), 40 kbps (@ 915 MHz), and 20 kbps (@868 MHz)
- Optimized for low duty-cycle applications (<0.1%)
- CSMA-CA channel access
  - Yields high throughput and low latency for low duty cycle devices like sensors and controls
- Low power (battery life multi-month to years)
- Multiple topologies: star, peer-to-peer, mesh
- Addressing space of up to:
  - 18,450,000,000,000,000,000 devices (64 bit IEEE address)
  - 65,535 networks
- Optional guaranteed time slot for applications requiring low latency
- Fully hand-shaked protocol for transfer reliability Range: 50m typical (5-500m based on environment)

B. *ZigBee/IEEE802.15.4 - Typical Traffic Types Addressed*

- Periodic data

- Application defined rate (e.g., sensors)
- Intermittent data
- Application/external stimulus defined rate (e.g., light switch)
- Repetitive low latency data
- Allocation of time slots (e.g., mouse)

Each of these traffic types mandates different attributes from the MAC. The IEEE802.15.4 MAC is flexible enough to handle each of these types.

- Periodic data can be handled using the beaconing system whereby the sensor will wake up for the beacon, check for any messages and then go back to sleep.
- Intermittent data can be handled either in a beaconless system or in a disconnected fashion. In a disconnected operation the device will only attach to the network when it needs to communicate saving significant energy.

Low latency applications may choose to the guaranteed time slot (GTS) option. GTS is a method of QoS in that it allows each device a specific duration of time each Super frame to do whatever it wishes to do without contention or latency

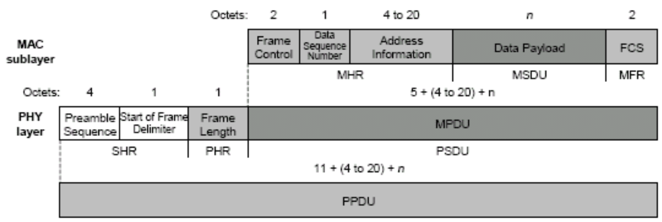


Fig.1: The data frame

The LR-WPAN standard allows the optional use of a superframe structure. The format of the superframe is defined by the coordinator. The superframe is bounded by network beacons, is sent by the coordinator (See Figure 2) and is divided into 16 equally sized slots. The beacon frame is transmitted in the first slot of each superframe. If a coordinator does not wish to use a superframe structure it may turn off the beacon transmissions. The beacons are used to synchronize the attached devices, to identify the PAN, and to describe the structure of the superframes. Any device wishing to communicate during the contention access period (CAP) between two beacons shall compete with other devices using a slotted CSMA-CA mechanism. All transactions shall be completed by the time of the next network beacon.

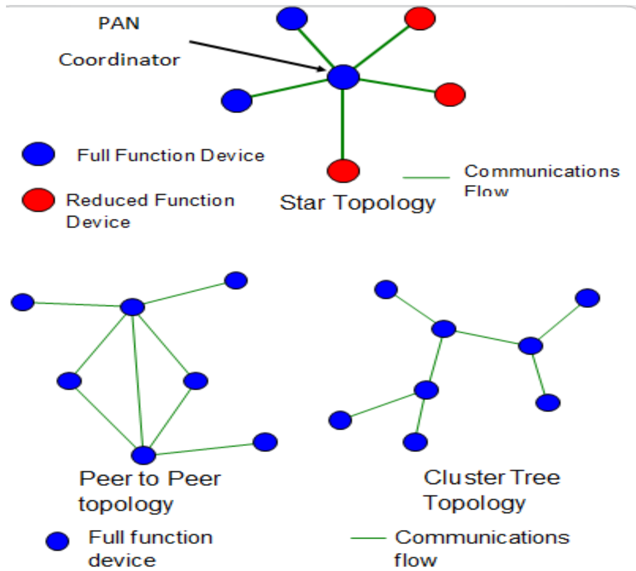


Fig.2: Super Frame Structure

For low latency applications or applications requiring specific data bandwidth, the PAN coordinator may dedicate portions of the active superframe to that application. These portions are called guaranteed time slots (GTSs). The guaranteed time slots comprise the contention free period (CFP), which always appears at the end of the active superframe starting at a slot boundary immediately following the CAP, as shown in Figure 5. The PAN coordinator may allocate up to seven of these GTSs and a GTS may occupy more than one slot period. However, a sufficient portion of the CAP shall remain for contention based access of other networked devices or new devices wishing to join the network.

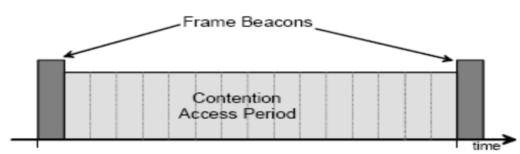


Fig.3: CAP Beacon Frames

All contention based transactions shall be complete before the CFP begins. Also each device transmitting in a GTS shall ensure that its transaction is complete before the time of the next GTS or the end of the CFP.

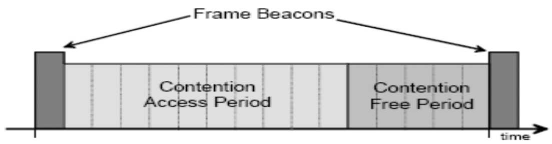


Fig.4: MAC Data Service Diagrams

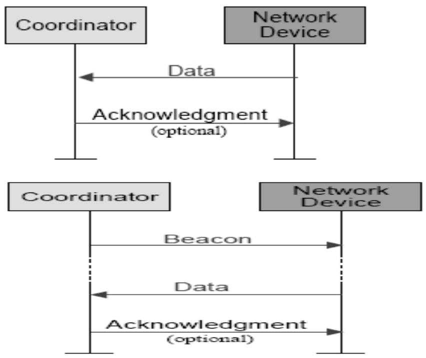


Fig.5: Acknowledgment Beacon network communication

C. MAC Primitives

i. MAC Data Service

- MCPS-DATA – exchange data packets between MAC and PHY
- MCPS-PURGE – purge an MSDU from the transaction queue

ii. MAC Management Service

- MLME-ASSOCIATE/DISASSOCIATE – network association
- MLME-SYNC / SYNC-LOSS - device synchronization
- MLME-SCAN - scan radio channels
- MLME- COMM-STATUS – communication status
- MLME-GET / -SET– retrieve/set MAC PIB parameters
- MLME-START / BEACON-NOTIFY – beacon management
- MLME-POLL - beaconless synchronization
- MLME-GTS - GTS management
- MLME-RESET – request for MLME to perform reset
- MLME-ORPHAN - orphan device management
- MLME-RX-ENABLE - enabling/disabling of radio system

An IEEE 802.15.4/ZigBee network requires at least one full function device as a network coordinator, but endpoint devices may be reduced functionality devices to reduce system cost.

- All devices must have 64 bit IEEE addresses
- Short (16 bit) addresses can be allocated to reduce packet size
- Addressing modes:
  - Network + device identifier (star)
  - Source/destination identifier (Peer to Peer)

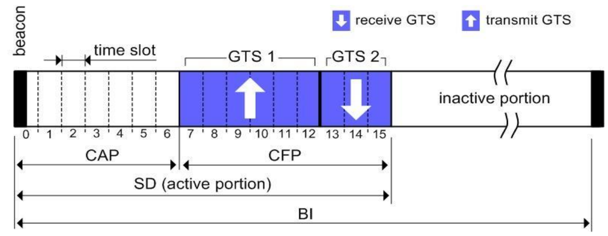
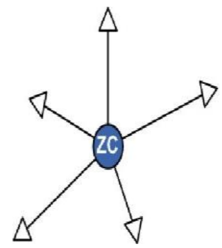
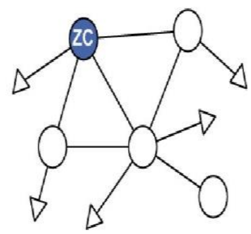


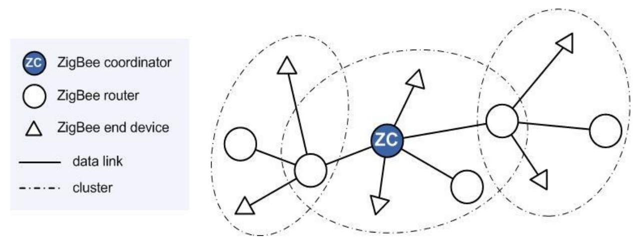
Fig.6: Super frame structure of IEEE 802.15.4.



(a) star topology



(b) mesh topology



(c) cluster-tree topology

Fig.7: IEEE 802.15.4/ZigBee network topologies

Regarding the node's role in the network, ZigBee specification defines three types of nodes: ZigBee coordinator, ZigBee router and ZigBee end device. The node that is capable to directly associate other nodes and can participate in multi-hop routing is referred to as ZigBee router (ZR). Any FFD operates in coordinator mode can act as a ZigBee router. An FFD operating in PAN coordinator mode acts as ZigBee coordinator (ZC). Every WSN shall include one ZigBee coordinator that holds special functions such as identification, formation and control of the entire network. ZigBee coordinator also participates in routing once the network is formed. The node that does not all flow association of other nodes and do not participate in routing are referred to as ZigBee end device (ZED). Any FFD or RFD can act as a ZigBee end device.

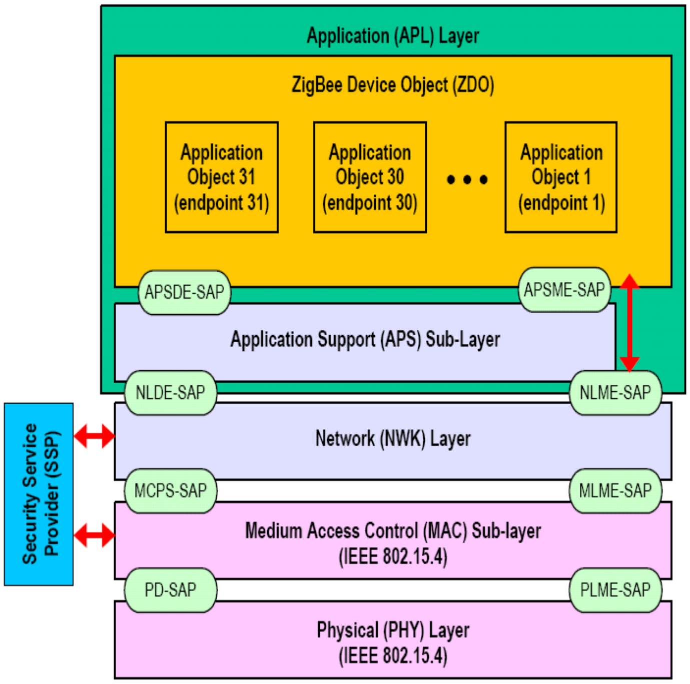


Fig.8: ZigBee Stack System Requirements

IV. Approach for ZigBee protocol design

The logical topology, based on a physical topology, defines a subset of wireless links to be used for data transmission. In the rest of the thesis, the notation topology will be used while meaning logical topology. One of the WSN topologies suited for predictable and energy efficient behaviours is a cluster-tree where the routing decisions are unique

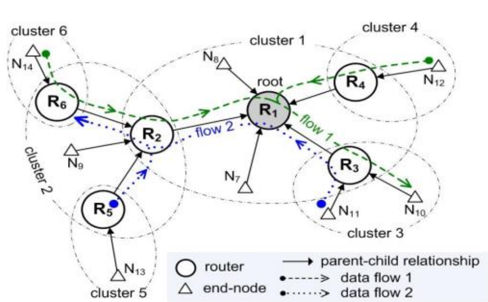


Fig.9: Cluster-tree topology with 2 time-bounded data flows.

The routers and end-nodes are two types of wireless nodes in cluster-tree WSNs. The nodes that can participate in multi-hop routing are referred to as routers (R_i). The nodes that do not all flow association of other nodes and do not participate in routing are referred to as end-nodes (N_i). In the cluster-tree topology, the nodes are organized in logical groups, called clusters. Each router forms a cluster and is referred to as its cluster-head (e.g. router R_2 is the cluster-head of cluster 2). All of its child nodes (e.g. end-node N_9 and routers R_5 and R_6 are child nodes of router R_2) are associated to the cluster, and the cluster-head handles all their transmissions.

Throughout this paper, the router and cluster-head are used interchange-ably since each router R_i acts as a cluster-head of cluster i for all its child nodes, and as a consequence, will send periodic beacons to keep them synchronized.

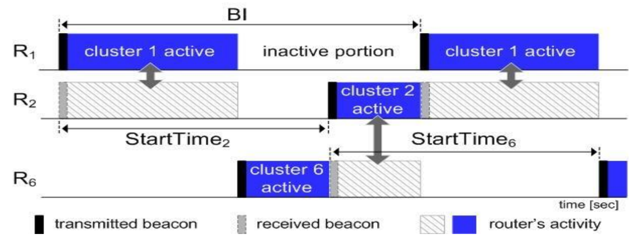
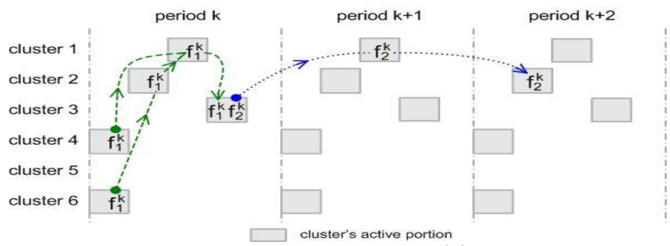


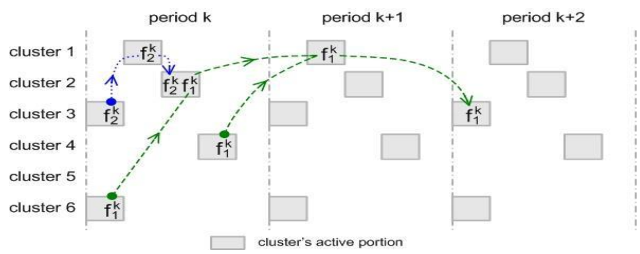
Fig.10: Timing among clusters 1,2 and 6

In cluster-tree WSNs, the flows traverse different clusters on their routing paths from the source nodes to the sink nodes. One execution of the flow (i.e. complete data communication from the source node/nodes to the sink node) is called a wave, and the notation f_i^k is used to denote wave k of the flow i. The flows are assumed to be transmitted with the same period; therefore wave f_i^k is followed by wave f_i^{k+1} for all flows and all waves with the same time separation. The cluster is active only once during the period [10], therefore all the flows in a given cluster are bound together. For example, the grey rectangles on the first line of Figure 4.3 show active portions of cluster 1 during three consecutive periods accommodating flows 1 and 2 in each period. The key problem is to find a periodic schedule, called Time Division Cluster Schedule (TDCS), which specific when the clusters are active while avoiding possible inter-cluster collisions and meeting all data flows e2e deadlines. The schedule is characterized not only by the moments when the clusters become active within the period, but due to the cyclic nature of the problem it is also characterized by the index of the wave for each flow in a given cluster.

Figure 4.3 shows two possible schedules of the example in Figure 4.1. Even if we relax on the lengths of transmitted messages and on resource constraints related to the cluster collisions, we have to deal with the precedence relations of the wave traversing different clusters. Since the flows have opposite directions in this example, the e2e delay minimization of the first flow is in contradiction with the minimization of the second flow. Figure 4.3a shows the case, when e2e delay of the flow 1 is minimized, i.e. the ordered sequence of clusters' active portions is in line with the flow 1 (starting with clusters 4 and 6 and following with clusters 2, 1 and 3), and therefore one wave of this flow ts into one period. On the other hand, the wave of the flow 2 spans over 3 periods while going against the sequence of clusters. Figure 4.3b illustrates the opposite case, when e2e delay of the flow 2 i



(a) Minimized end-to-end delay of flow 1 (dashed line)



(b) Minimized end-to-end delay of flow 2 (dotted line)
Figure 11: Schedules for data flows

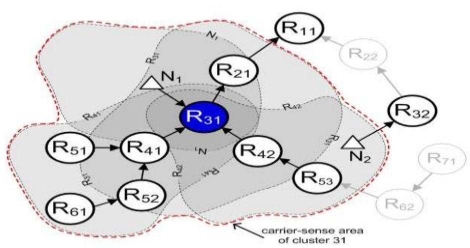


Fig.12 : The carrier-sense area and collision domain (bold routers) of cluster 31

V. CLUSTER MODEL

The cluster-tree is considered as a logical topology of WSNs. the routers and end-nodes are referred to as Rij (i.e. the jth router at depth i) and N, respectively. The routers and end-nodes having sensing capabilities are generally referred to as sensor nodes. The depth of a node is defined as the number of logical hops from that node to the root. Note that the root is at depth zero and, by convention, trees grow down. This section aims at specifying the worst-case cluster-tree topology which contains the maximum number of nodes in the network, i.e. the network topology configuration that leads to the worst-case performance. In the worst-case, when the maximum depth is reached, and all routers have the maximum number of associated child end-nodes and routers, the topology will be balanced (regular). However, a particular WSN can have unbalanced or even dynamically changing cluster-tree topology, but it can never exceed the worst-case topology, in terms of maximum depth and number of child routers/end-nodes. The irregularities in a particular topology introduce some pessimism to the analysis. On the other hand, given any network deployment several cluster-tree logical topologies can be found. Depending on the application, the system designer should select the most regular topology in design time to reduce the pessimism of the worst-case results.

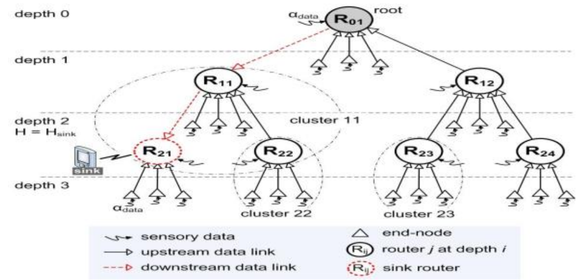


Fig.13: The worst-case cluster-tree topology model

In the worst-case, all sensor nodes are assumed to contribute equally to the network load, sensing and transmitting sensory data upper bounded by the affine arrival curve $_{data} = b_{data} + r_{data}$ t (Figure 14), where b_{data} is the burst tolerance and r_{data} is the average data rate. The affine arrival curve can represent any type of traffic, assuming that it can be bounded. It can represent a periodic or aperiodic traffic [6], or any other random traffic (VBR traffic). This is the main reason for using this simple but effective and general arrival curve model: to be independent of any specific pattern/distribution of traffic.

In case of different sensory data traffic, $_{data}$ is considered to represent the upper bound of the highest sensory data traffic among all sensor nodes in the network. The analysis will lead to some pessimism if the variance between the highest sensory data traffic and the others is high, i.e. the pessimism increases with the variance. However, in many WSN applications

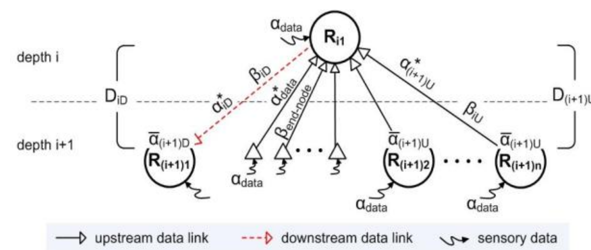


Fig.14: General data flow model with corresponding arrival and service curves.

The variance between the sensory data is likely to be small, since the sensing events are commonly reported by similar data types (e.g. single-precision floating-point number which occupies 32 bit).

VI. CONCLUSION

The unreliable and time-varying characteristics of wireless channels can be minimized using the acknowledgement and retransmission mechanisms. On the other side, each retransmission decreases guaranteed bandwidth and increases communication delay as depicted in Figure 13. the guaranteed bandwidth of one time slot and the theoretical worst-case end-to-end delay as a function of the number of retransmissions (parameter macMaxFrameRetries) for Hsink = 0. The guaranteed bandwidth of one GTS time slot is obtained multiplied by the duty-cycle, which is equal to 12.5%. It can be observed that the minimum guaranteed bandwidth of one time slot is equal to 130 bps when three retransmissions are enabled. To obtain comparable end-to-end delays, the same number of time slots must be allocated to each node when consider different number of retransmissions. Hence, the average arrival rate of sensory data must be reduced to rdata = 40 bps, for example. According to the IEEE 802.15.4 standard, the inter-frame spacing IFS is equal to LIFS or SIFS depending on the length of MAC frame. The worst-case end-to-end delays obtained by per- flow approach introduces less pessimism than other

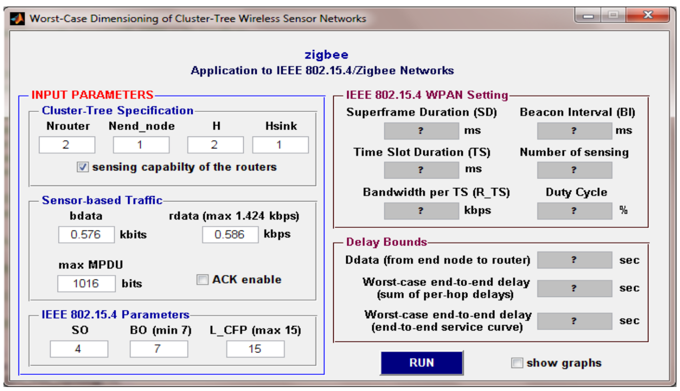


Fig.15: Worst case to design cluster tree WSN

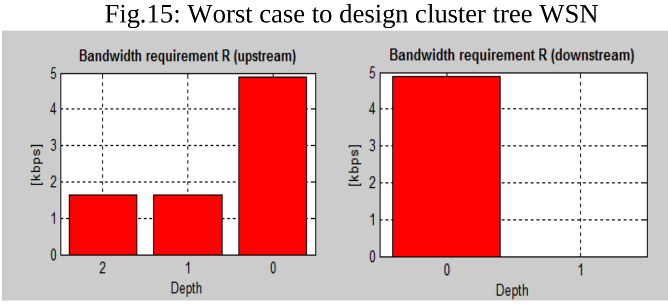


Fig.16: BW Require for upstream and downstream

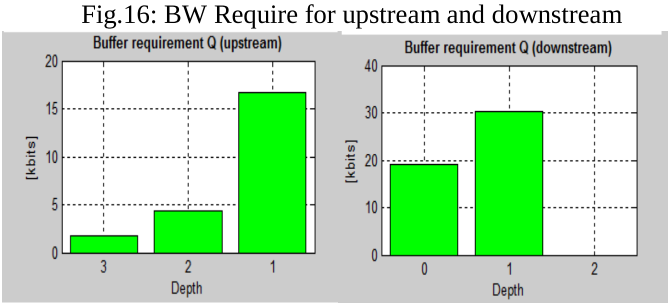


Fig.17: Buffer Requirement for upstream and down stream

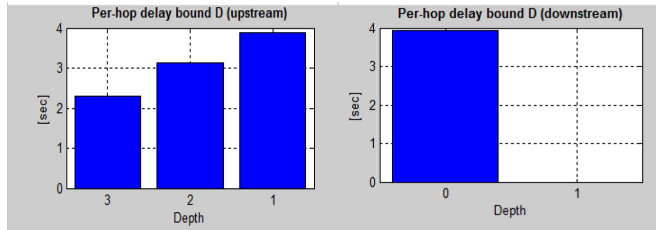


Fig.18 : Per-hop delay bound for upstream and downstream

Modeling the fundamental performance limits of Wireless Sensor Networks (WSNs) is of paramount importance to understand their behavior under the worst-case conditions and to make the appropriate design choices. In that direction this chapter contributes with a methodology based on Network Calculus, which enables quick and efficient worst-case analysis and dimensioning of static or even dynamically changing cluster-tree WSNs where the data sink can either be static or mobile, i.e. can be associated to any router in the WSN. The proposed analytical methodology (closed-form recurrent expressions) enables to guarantee the routers' Buffer size to avoid Buffer over flows and to minimize clusters' duty-cycle (maximizing nodes' lifetime) still satisfying that messages' deadlines are met.

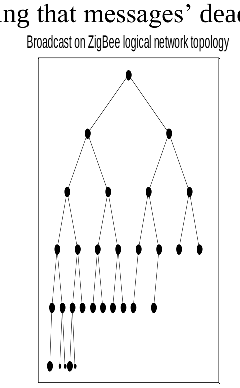


Fig.19: Broadcast ZigBee Logical Topology

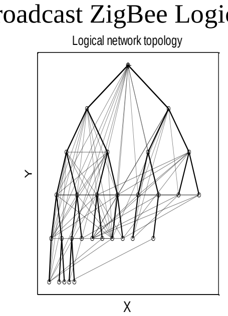


Fig.20: Logical Network Topology

During the update process, just some links between correspondent routers are reversed, thus not impacting the entire network (involving the minimum number of routers/messages), so normal network operation can quickly be resumed. As a result, this algorithm requires a minimum amount of control-related traffic and reduces network inaccessibility times.

Following find are observe when selection of value of Cm and Lm.

1. As depth level increase delay parameter increase and it maintain constant after a level
2. As depth level increase number of receive increase
3. As increase as connection or Cm value increase than number of Non forward node increase

In future scope we will increase the more parameter like bandwidth requirement, buffer or throughput requirement and delay parameter for upstream and downstream communication in ZigBee structure

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