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An Advanced Zigbee Stack for Effective Data Handling and Management

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Abstract: Wireless technologies and their behavior are hard to predict due to their in-deterministic behavior. In the power sector automation domain, applications requiring high availability and reliability are using wireless technologies. Therefore, it is necessary to predict the behavior of wireless networks. Naively built ZigBee networks often have to deal with overutilization and system breakdowns as a result. Over-utilized networks even lack in timeliness of packet reception. Therefore, analysis resulting in estimations for predicting ZigBee behavior is necessary. When new approaches are developed to predict a systems' behavior, validation of the concept is necessary to rely on it. Validation of system concepts can be performed by proving it by simulating the system and comparing the results. By using the results of the simulation, the correctness of the prediction approach is emphasized. Such approach can then be used to detect limiting constraints for ZigBee networks. Estimations regarding the channel utilization can help detecting bottlenecks in the network. Protocol overhead predictions reveal the necessity for management packets that cause additional network traffic. In general, the knowledge of ZigBee's limits helps optimizing networks. In this paper implementation of additional modules in the existing stack has been proposed, whereby the data packets routing is significantly improved in the network. The graph and the corresponding screen shots are standing example for improved system and performance.

Key words: Zigbee · Packet management · Packet loss · Trafficking

INTRODUCTION

Because of no global standards so far in wireless sensor networks, the ZigBee plays vital role in most of the wireless application [1-3]. The behaviour of ZigBee has to be examined to check the feasibility of desired network structures in advance. Since no sufficient method for predicting ZigBee networks exists, new approaches to fulfil this task are necessary. The required density of network nodes and the maximum load a network can manage have to be considered in these concepts. The best simulation environment to simulate ZigBee networks is chosen as NS-2 because most of the open-source simulator environments are on a lower development level than the commercial environments. It is a discrete event network simulator within a series of network simulators developed under open-source licenses. The GUI of ns-2 as well as ns-3 consist of aTcl/tk interface. Back end is driven by C++ and front-end by TCL/Tk. Some of zigbee applications are A Design of Greenhouse Monitoring & Control System Based on ZigBee Wireless Sensor Network [4], ZigBee Based Multi-Level Parking Vacancy Monitoring System [5], Research of Wireless Sensor Networks based on ZigBee for Miner position [6] Applications of Wireless Sensor Networks in Environmental Monitoring [7].

Understanding of Current Existing Scenario: The Scenario is considered as number of powered tower lines and UG cables run through. Every tower installed with Zigbee based power and tower line monitoring system. Electrical parameters like voltage, current and frequency being sent to server through Zigbee network to the server. The data transmission takes place through node hopping in the network.

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Similarly other parameters like 'tower tilting, inclination of tower and temperature off-shoot" etc… are being sent in similar manner as mentioned above. Whenever there is a inclination of the tower or vibrations at the tower or any tilting, corresponding scenario is taken as a highest priority and the server gets immediate communication through the same network as mentioned above [8-10].

The problem is during abnormal events which causes repeated asynchronous data bursts coming from the sensor nodes prevailing/normal zigbee frame work cannot accommodate it because of its 128 bytes payload length which is zigbee standard defined. Traffics and packet loss are also a serious issue in the existing protocol stack [3]. To be more precise consider this eg: Assume zigbee based power line monitoring nodes are installed on series of nodes and all nodes are relaying their data synchronously to the receiving base station, when abnormal events occur there will be uncontrollable sensor traffic coming out from different nodes , the server will not be able to handle all the sensor data, it will lose/drop vital information's coming out from all sensors. As of now there is no such mechanism to collate or handle all abnormal-event raised/asynchronous sensor data traffic coming out from asynchronous nodes. Biggest bottleneck prevailing as of now is once the nodal traffic increases server cannot receive remaining data from all other nodes, What happens is successive repetitions all frames are filled up with asynchronous abnormal data, drop data from other nodes (Data gets choked). It is not updated with other node's information.

Such scenarios prevail due to non-handling of fast varying data at the Zigbee protocol stack level. Standard/prevailing zigbee framework architecture cannot handle such conditions. The generic Zigbee stack has an OSI model. The actual proposed architectural solution that will overcome the above problem/bottleneck by inclusion of additional features as discussed below.

Representation of One Zigbee Node in Existing Scenario: In the current scenario, every lamp post is assumed as one Zigbee node. The functional block diagram of such nodes is represented as given in the Fig. 1 below. Series of such nodes form a network to send and receive data. From the functional behaviour in the network, it is assumed that each node in the network performs both FFD and RFD functionalities of Zigbee.

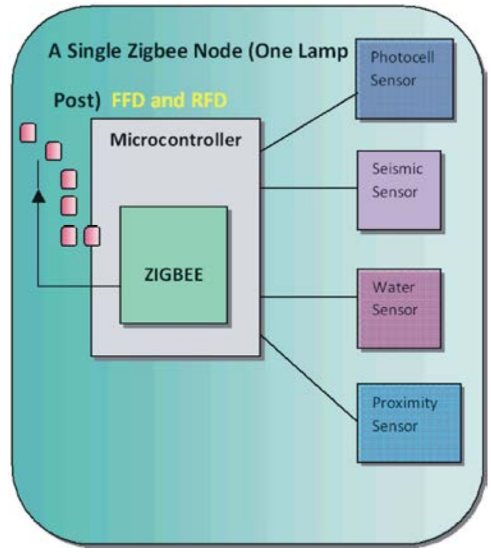


Fig. 1: A Single Zigbee Node (One Lamp Post)

Representation of Existing Network Scenario: In the existing scenario, six nodes are taken for sample representation as given in the below Figure 2. In the below Figure 2, node 3 is the problematic node or a node with some emergency. Under this situation, the data rate of node 3 becomes increased and transmits to the next nodes continuously. The other nodes namely 4, 5 and 6 will receive the data of node 3 and pass to its next nodes as given in the figure. The problem is when such situation occurs; the other nodes (4, 5 and 6) become dormant to process and send its own data except the data of node 3.

So after node 3, the rest of the nodes in the network will keep sending only data of node 3 for ever. The data from previous nodes (1 and 2) are being dropped or rejected continuously by the node 3 as seen in the figure below 2. This type of scenario arises due to the lack of following implementation:

- Packet Scheduling Management
- Buffer handling Management
- Data control management
- Interrupt Management

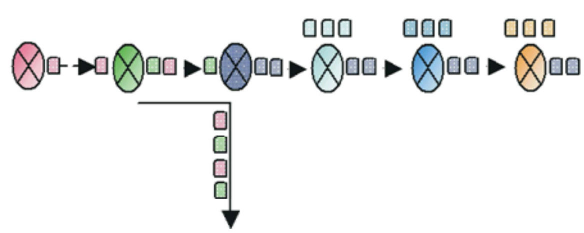


Fig. 2: Existing Network Scenario

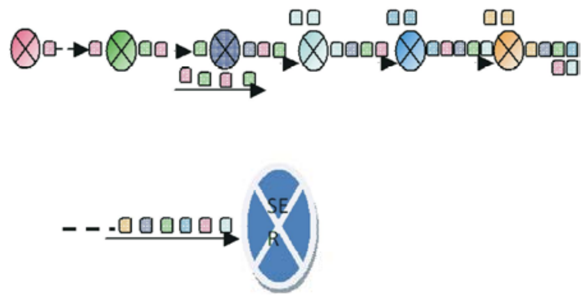


Fig. 3: Graphical representation of transmission of Zigbee data packets in the proposed solution

Representation of the Proposed Solution: The Fig. 3 shows the graphical representation of transmission of Zigbee data packets in the proposed solution. The defect node (Node 3) in the proposed architecture does not reject data packets coming from the node -2. It receives the data packets from node – 2 and process and send to node -4 without losing or dropping any data packet.

Detailed Review of Proposed Solution: Faq: Priority Based AODV algorithm is used here to collect data from previous node and send to next node. Our assumption about the existing scenario is something similar to linear hop to hop communication between source and destination.

Improved Algorithm Design

Neighbour Table Definition: If the two nodes can communicate directly within one hop, we say that the two nodes are neighbours. Due to the RFD device storage capacity is weak, so it only stores its neighbour list for the FFD equipment and RFD equipment, particularly need to store the neighbour list of it. FFD nodes in the network record the adjacency between the nodes and other nodes through the neighbour list Nlist, as shown in below.

ADDR	DT	NP

In the Nlist, there are three fields: ADDR: neighbour nodes address DT: neighbour nodes device identity bits, 1 indicates that the neighbour node is FFD device, with a routing function; 0 indicates that the neighbour node is RFD device, does not have routing functions and only send and receive data. NP: neighbour node residual energy identity bits. 1 indicates saturated node, 0 indicates non-saturated node.

Modified Algorithm Flow – Priority Based Aodv:

While (task (k, i)) //task means any packet receiving that node i and K means level
{
If (that is real time data)
{
Put that is in PR1 queue
}
Else if (node at which data sensed that's not at lowest level) //data also non real data
{
If (data is non local) //check whether it came from lowest level node
{
Put in PR1 Queue
} else {
Put in PR2 Queue // local data sensed at that node itself
}
}
//Some time slot given to level consider total time slot is Tk at k level
Consider data sensing time Ts
Remaining time T1(K) = Tk –Ts
Let total real time task at (NODE)i at level at Level k - nk(pr1)
Proctime(Pr1)k is total time for pr1
If (Proctime (Pr1)k<T1(k))
{
All pr1 tasks of node (i) at l (k) are processed as FCFS

Remaining Time T2 (k)= T1(k)-ProcTime(Pr1)k
Proctime (Pr2)k is total time for pr2
If (Proctime (Pr2) k < T2(K))
{
All pr2 tasks are processed as FCFS pr3 tasks are processed as FCFS for the remaining time,
T3 (k) = T2 (k) - procTimepr2 (k)
} else {//this loop for if pr1 task time greater than Remaining time T2 (k)
pr2 tasks are processed for t2(k) time
no pr3 tasks are processed
}//end of inner if loop
} else { //this loop for if pr1 task time greater time than total time slot of that level
only pr1 tasks are processed for T1(k) time
no pr2 and pr3 tasks are processed
}
//after this block for pre-emptive type if any task processing at that time any higher priority task comes means its giving priority to that task
If (Pk_Valid_Time<Threshold)
{

Packets moved into PR1
} else { {
Non Pre-emptive process
}
} //end of if
}//end of while

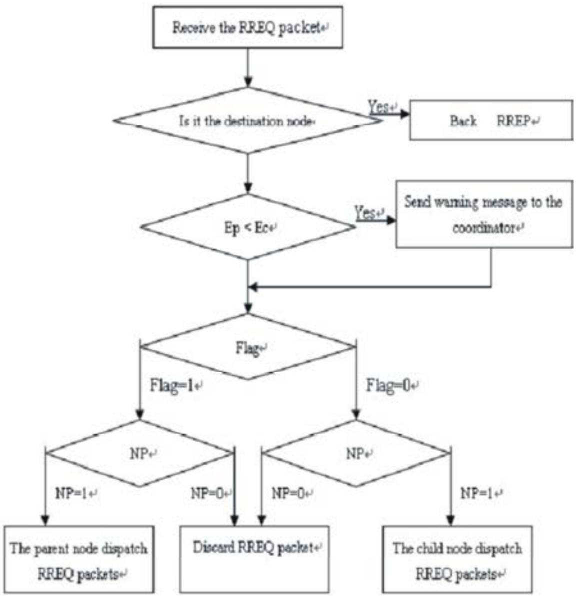


Fig. 4: Algorithm Flow for AODV

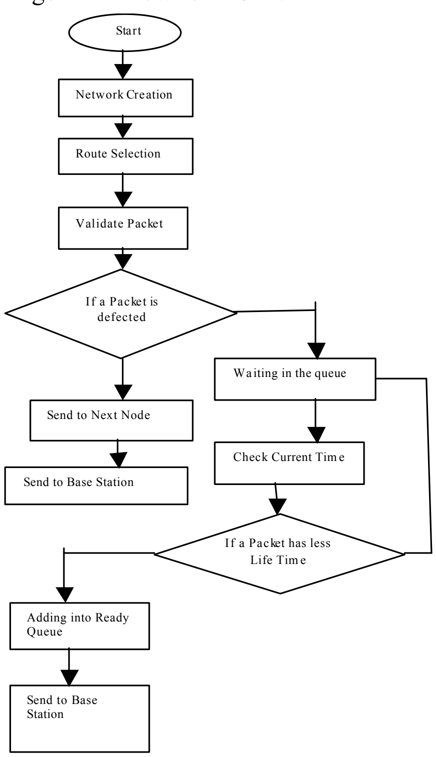


Fig. 5: Algorithm Flowchart for Priority Based AODV in the Proposed Solution:

Importance of Priority Based Aodv Algorithm: The constraint or the limitation of the existing system is that the data rate of defected or problematic node goes high. Also this particular node keeps sending and creates the traffic in the network. In this scenario two things have to occur.

- Handling of Urgent data and passing through network.
- Also passing every nodal information/data through network without getting lost.

So, to satisfy the above two scenarios, Priority Based Queuing Algorithm Is introduced.

Here, we are categorizing the priorities in two different ways:

- Routing of Neighbour node's packet
- Life Time of the packet. This means if any packet reaches its dead line, it is considered as packet with high priority.

We are using modified AODV as priority based AODV for gathering data. Also implemented the given modules (below) to receive and send data without packet loss occurring in the network.

DSA – Data Scheduling Activity
IAMI – ISR Handling Activity for multiple Interrupts (IAMI)
DCMA – Data Handling and Control Management Activity (DCMA)
BMFVD - Buffer Management Activity for multiple interrupts for fast varying data (BMFVD

Importance and Advantages of Zigbee over Others [1, 2]:

	Data Transfer Rate	Network Range	Network Topologies	Network Size	Energy Consumption
Zigbee	Up to 250Kbps	10m-100m	Star, mesh & Other Generic topologies	Nodes up to 6500	Much lesser than Bluetooth
Bluetooth	Up to 1Mbps	10m	Point-Point: Master Slave	Slaves up to 7	Lesser than Wi-fi
Wi-fi	Up to 54Mbps	10m-100m	Point-Point	Up to 2007	Need good Battery Back up

Zigbee Characteristics: 2.4GHz and 868/915 MHz dual PHY modes. Represents three license-free bands: 2.4-2.4835 Ghz, 868-870 MHz and 902-928 MHz [1, 2]. The number of channels allotted to each frequency band is fixed at sixteen (numbered 11-26), one (numbered 0) and ten (numbered 1-10) respectively. Low power consumption, with battery life ranging from months to years. Maximum data rates are fixed as 250 kbps @2.4 GHz, 40 kbps @ 915 MHz and 20 kbps @868 MHz. Addressing space of up to 64 bit IEEE address devices, 65, 535 networks High throughput and low latency for low duty-cycle applications (<0.1%) access using Carrier Sense Multiple Access with Collision Avoidance (CSMA - CA) 50m typical range Fully reliable "hand-shaked" data transfer protocol Supported Different topologies: star, peer-to-peer, mesh.

Zigbee Phy Frame Structure [1, 2]:

Sync Header (5 Bytes)		Phy Header (1 Byte)		PHY Payload (128 Bytes)
Preamble- 4 Bytes	Start of Packet Delimiter – 1 Byte	Frame Length 7 Bits	Reserved	Data Unit

The Standards Available: Zigbee follows 1EEE 802.15.4 Standard and this defines lower layer of protocol stack: MAC & PHY. Zigbee specification defines upper layer of protocol stack: Network to Application including application profile.

Existing Zibee Stack: The Fig. 6 below shows internal components of Zigbee Stack Flow [1, 2].

The Modified Stack: The Table 2 represents the four modules added in the stack.

IAMI	BMFVD
DCMA	DSA

The Fig. 7 represents placing of the four modules in the stack layers.

The Wireless Communication Structure - Sensor - Cluster Heads -Sink: Zigbee communication structure between nodes is given below in Fig. 8.

Our Setup or Network Assumed: The Fig. 9 shows simulation environment. Here, all the nodes are arranged as linear multi-hop network. Together nine nodes are taken for the simulation. Different colors are chosen to indicate the packets/data from different nodes. The scenario shown in the Fig. 9 is a screen shot for proposed solution. The one which is red colored is considered a problematic node in the network (Ref Fig. 12 & Fig. 13). Here, the node-4 which was considered as problematic in existing scenario is passing all the data received from previous nodes and its own data to other nodes along the network (Proposed scenario shown below). Also refer Fig. 10 and Fig. 11.

The legend shows the different colours used to distinguish the packets associated with each node. The screen shots (Fig. 9, 10 & 11) are the different scenarios taken for proposed solution. In Fig. 9, the red colored node-4 is the node that was considered running under emergency in the existing scenario. Here in proposed scenario, the same node-4 receives the data packets from its previous nodes (1, 2 & 3) and passing them to the next node-5 along with its own high priority data. In the proposed solution, the data management, priority data scheduling and buffer management for queuing high data rate packets are implemented. As a result, scheduling and passing of data of every node through the network is achieved without any data dropping or packet loss. The screen shots shown (Fig. 9-11) are typical implementation of proposed solution. The total simulation run time taken is 4 seconds.

Importance of Ns2 Simulator: Among simulations, Ns2 plays a major and vital role in the networking research and education. And highly useful in Protocol design, traffic studies and protocol comparison. The principal idea is that if a system can be modelled, then features of the model can be changed and the corresponding results can be analyzed. As the process of model modification is relatively cheap than the complete real implementation, a wide variety of scenarios can be analyzed at low cost (relative to making changes to a real network).

Screen Shots- Packet Loss: The Fig. 12, Fig. 13 and Fig. 14 are the screen shots of existing (Packet Loss/Drop) scenario. The node no.4 is acting with emergency and keeps sending its own data with high data rate and dropping all the data received from other nodes.

Fig. 12, Fig. 13 and Fig. 14 represent three different study of present scenario. Here, Node Zero sends its data packet to node-1. In turn node-1 passes it to node-2 and node-2 to node-3 and consecutively to the main server. When any one of the node (node-4 as example) becomes under emergency, then it starts sending data packets with high data rate and passing this emergency data to the rest of nodes (node-5, node-6 node-7 and etc). During this phase, the rest of nodes receive only this emergency data and pass through and become dormant to handle its own data that is supposed to be passed through the network. Due to lack of internal data management, the node-4 keeps dropping packets received from previous nodes (Node-0, 1, 2, 3). This represents typical existing scenario and the screen shots (Fig. 12-14) represent the same. The total simulation run time taken is 4 seconds.

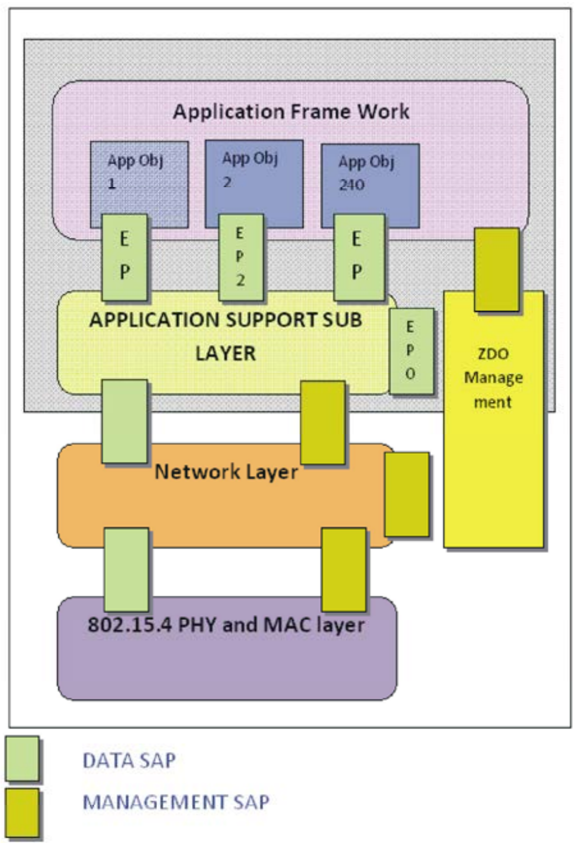


Fig. 6: The Existing Zigbee Stack

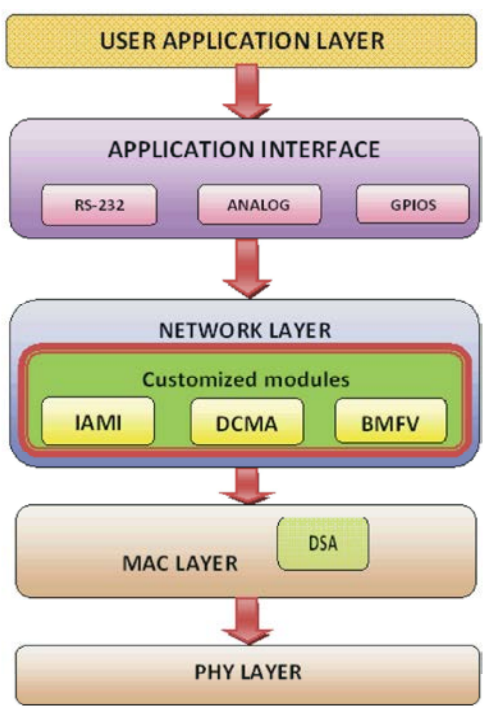


Fig. 7: The modified stack

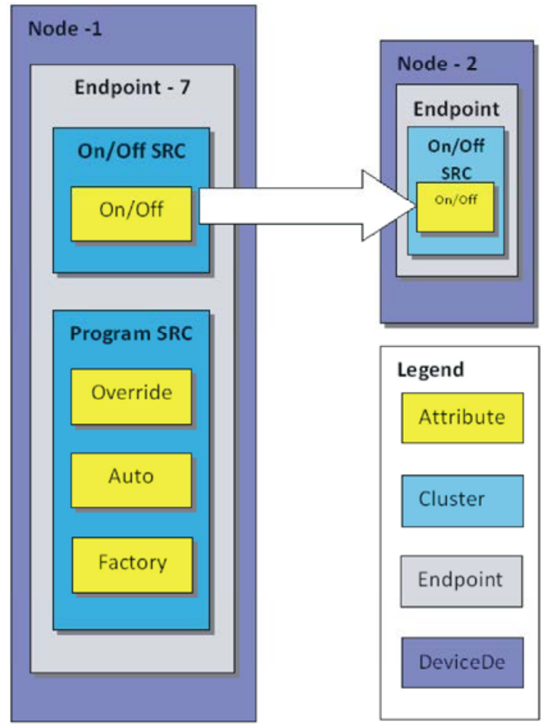


Fig. 8: The Zigbee Communication Structure

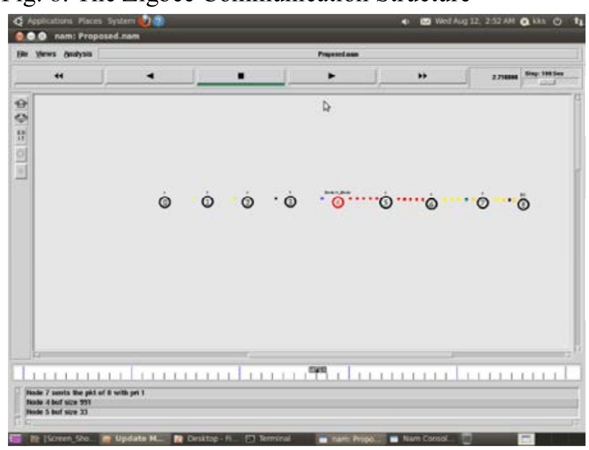
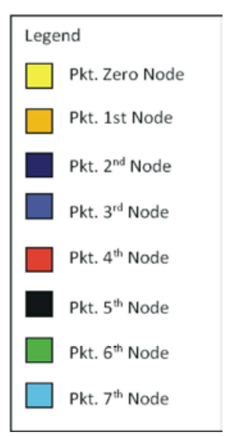


Fig. 9: The proposed scenario -1



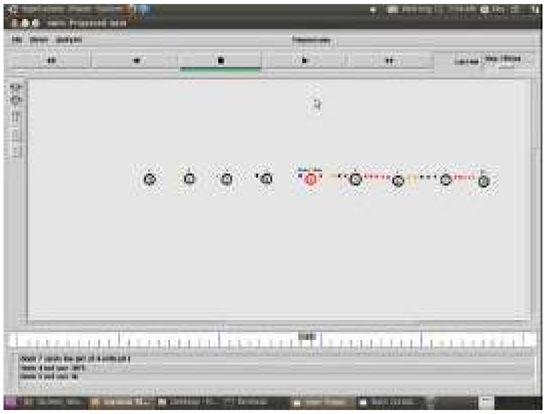


Fig. 10: The proposed scenario -2

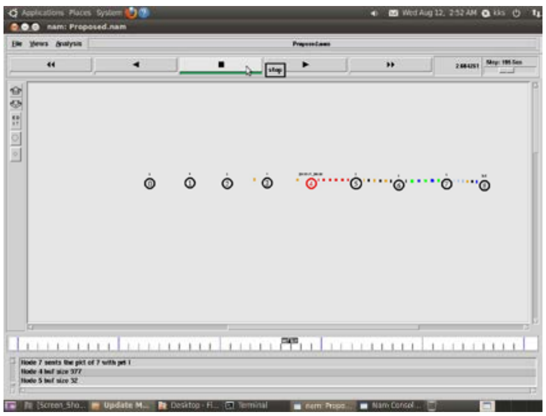


Fig. 11: The proposed scenario -3

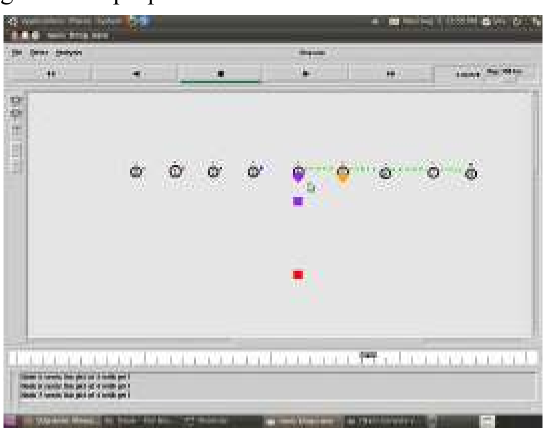
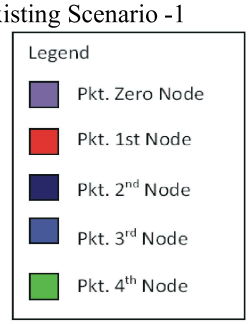


Fig. 12: The existing Scenario -1



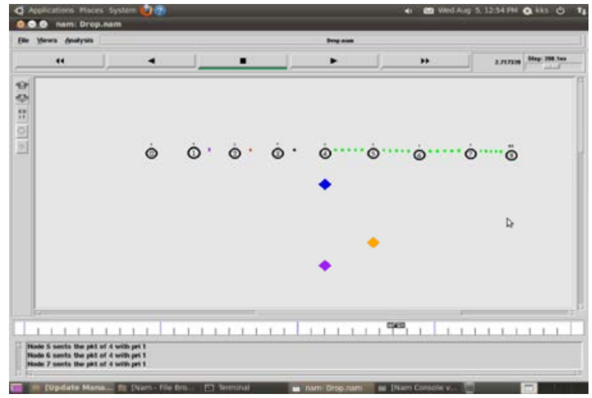


Fig. 13: The existing Scenario -2

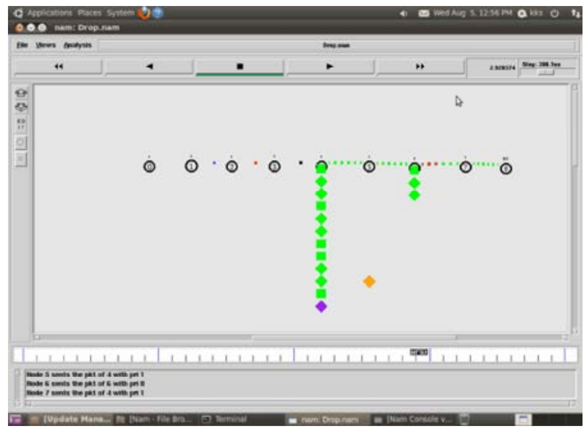


Fig. 14: The existing scenario -3 - Packet Loss due to high data rate and queue over running – Traffic

Comparison of Performance of the Existing and the Proposed Zigbee Stack: The following four modules are introduced to have better routing of packets through the network. The overall packet handling mechanism is improved for better performance and packet delivery without loss. Packet delivery under emergency condition is guaranteed without losing or dropping in the network by the nodes.

DSA - Data Scheduling Activity
IAMI - ISR Handling Activity for multiple Interrupts (IAMI)
DCMA - Data Handling and Control Management Activity (DCMA)
BMFVD - Buffer Management Activity for multiple interrupts for fast varying data (BMFVD)

The analysis of Zigbee performance is purely specific to the network environment that is connected to. In general for the performance analysis, three key components will be considered Such as:

- Node connectivity,
- Packet loss rate and
- Transmission Throughput

Zigbee performance in two scenarios with and without modification is captured through graphs and screen shots. These are depicted in Fig. 9-11, Fig. 12-14 and graphs (Fig. 15 & Fig. 16).

Existing Scenario: Two scenarios are captured such as existing and proposed. Readings are observed for both scenarios. The Fig. 15 below shows existing scenario. In existing, packets loss is plotted against time. The X-Axis represents time and Y-Axis represents Packet loss or drop. The scale of Y-Axis is taken in terms of 106. So, every number along Y-Axis represents the number multiplied by 106.

The scale of X-Axis is taken 0.5 seconds up to 4 seconds. The time period considered for data activity (transmission) is only four seconds only. Readings (packet loss) are taken from the simulation run time and plotted along Y-Axis against time on X-Axis. The red colored plotting shows that the packet loss or drop gradually increases from the node-4 and reaches a high and drops down deeply as an inclined path to zero as capture ends at 4th second. This is well observed and clearly captured as screen shots (Fig. 12-14).

Proposed Scenario: Two scenarios are captured such as existing and proposed. Readings are observed for both scenarios. The Fig. 16 below shows the graph plotted for proposed scenario. In proposed, packets delivered are plotted against time. The X-Axis represents time and Y-Axis represents the number of Packetsdelivered. The scale of Y-Axis is taken in terms of 106. So, every number along Y-Axis represents the number multiplied by 106 .The scale of X-Axis is taken 0.5 seconds up to 4 seconds. The time period considered for data activity (transmission) is only four seconds only.

Measurements for packets delivered are taken from the simulation run time and plotted along Y-Axis against time on X-Axis. The pink colored plotting shows that the packet delivered by node-4 increases gradually and reaches and keeps delivering the packets to the nodes continuously against time. This similar behavior is well seen and clearly captured as screen shots (Fig. 9-11). The highlighted region shows the packets delivery done by the node-4.

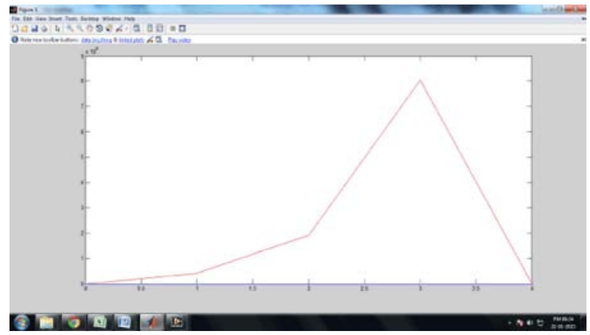


Fig. 15: Packet loss rate in exiting zigbee stack

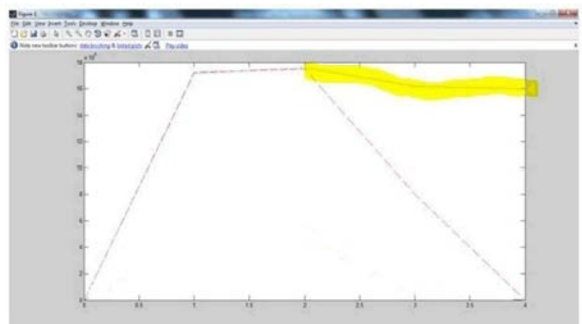


Fig. 16: Comparison Of Packet Loss Rate In Existing And Proposed Zigbee Stack

With an implementation of additional modules in the proposed system, the data packets routing is significantly improved in the network. The graph and the corresponding screen shots are standing example for improved system and performance.

CONCLUSION

Based on the inputs received, the whole objective of the work was to simulate the existing scenario and propose a solution for the current scenario. After the completion the following are
our observations:

- The study and understanding of the current scenario about Zigbee network was clearly done.
- Identified the problems in packet handling mechanism in the current scenario.
- Replicated simulation environment successfully for the problematic scenario using NS2 simulator.
- Taken different screen shorts for packet dropping scenario successfully.
- Done the architect to handle packet handling and scheduling mechanism for the proposed solution.

- Implemented four different modules to handle packet dropping scenario.
- Executed simulation with implemented modules successfully.
- Tested proposed solution in the simulation environment and observed no packets dropping.
- Taken the screen shots for the proposed solution.

To conclude, the effectiveness of the implementation of the four modules is seen in the simulation environment. The comparison of two scenarios is done and observed using simulation.

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