CHAPTER 3

MULTI-CLUSTER MULTI-CHANNEL MONITORING (MMM) ALGORITHM

3.1. INTRODUCTION

Wireless Sensor Networks (WSNs) typically have no fixed infrastructure like wired network. In the large monitoring region, the wireless sensor nodes are deployed randomly. Moreover, the longevity of the network, the maximum coverage range, the availability of the services, connectivity and the scalability of the network are significant design goals to ensure the improvement in the network performance and provide services at every part of the deployment area (Akyildiz et al 2002 and Verdone et al 2008).

The scalability and longevity of the network can be achieved by curtailing the communication path in terms of a number of hops. The use of multiple sink nodes in WSNs have been advised as one possible way to make the network management easy, shorten the communication range in terms of number of hops and to increase the scalability and lifetime of the network. Thus the WSN with multiple sink could be divided into a number of clusters with one cluster head node. To solve the channel overlapping and interference problem and to increase the data collection, the Multi-cluster topology with Multichannel communication has been proposed in this Thesis.

Exiting Medium Access Control (MAC) protocol in literature discussed the collision problem in single-hop or light loaded traffic. But, it was not the best solution for large network with heavy traffic. The large wireless sensor network with heavy traffic requires the proper design of channel assignment, channel coordination and collision avoidance. The multiple-rendezvous multichannel MAC protocol (MM-MAC) proposed by Chao et al (2013) addressed these problems. The feature to speeds up the channel negotiation, contention problem and collision reduction has been discussed.

The fundamental concept of designing multichannel addresses the issue such as “which node can access which channel and when”. The proper channel utilization of single-transceiver sensor node and proper utilization of the available frequency band are a challenge for researchers. This Chapter focuses on how to utilize the frequency band of MAC with proper channel assignment algorithm and how to avoid the channel interference by selecting appropriate channels.

The performance improvement and the scalability of the network can be obtained by using two-tiered hierarchical architecture. The first level nodes are cluster member nodes and next level nodes are sink nodes. Kone et al (2010) proposed the cluster-based multi-channel system for improving performance of wireless multi-sink sensor networks. The cluster head in the network was considered as sink and the channel assignment also varied from CH to CH. The same frequency channel has been assigned to the alternate CHs. This channel assignment concept reduces the interference but the algorithm proposed in this Chapter is discussed how to get the maximum interference avoidance by proper channel assignment and channel switching strategy.

Nowadays the multichannel communication is applied to various real time applications such as under-water sensor applications, tactical surveillance, disaster warning etc. The performance degradation of the wireless sensor network happens due to some serious problems like collision.

To avoid transmission collision, transmission scheduling algorithms were proposed in the underwater acoustic sensor network protocol by Nguyen et al (2008) and the multichannel MAC protocol for Under Water Sensor Network was designed by Chao et al (2013).

Maximization of the data collection is the most vital motivation of the research. One way of maximizing data collection is proper design of routing protocol which is discussed by Mottola & Picco (2011), Samundiswary & Anandkumar (2012). Proper deployment of the network also maximizes the data collection.

3.2. LITERATURE SURVEY

The routing protocol proposed by So & Vaidya (2007) addressed the issues such as channel assignment based on traffic load, channel switching etc and also explained how to achieve the channel load balancing by dynamic selection of routes based on the current traffic condition. The routing discussed in the literature ensures that every node in the network had at least one route to access point during channel switching and channel association with access point. The load balancing among the channels have been achieved using weighted metric concept, eventhough this protocol also had some limitations such as more number of channels were assumed and the load metric did not explain how to achieve the high throughput gain for spatial reuse.

The Distributed Information Sharing (DISH) approach discussed by Luo et al (2009) developed a protocol design in WSN. In this approach, the control information was shared between nodes thereby, more informed decision has been taken by the node. The Cooperative Asynchronous Multichannel MAC protocol called CAM-MAC was designed based on the DISH approach. The channel selection in the DISH was in random manner, it means that a node in a network randomly selects any free channel from the list. One more assumption used by the DISH is the node which always selects the mostly recently used data channel if other channels are busy with some other nodes. In this approach one channel was fully dedicated as control channel for nodes to distribute, collect, and share information. The Multi Channel Coordination (MCC) problems are also addressed. The MCC was solved by using the DISH approach; it allowed the neighbouring node to alert the transmitter-receiver pair of the problem to avoid the retransmission and collision problems.

The role of multichannel communication to improve the performance of the wireless sensor networks was discussed by Incel (2011). The author explored how multi-channel communication can decrease the effects of interference factor, and can improve the channel capacity. The fundamental challenges using multi-channel protocol in terms of channel switching, channel overlaps and channel coordination have also been identified. The various capacity issues in WSN and the limiting factors that affect the capacity improvements have been addressed. The author Incel (2011) studied the different multichannel aspects which minimize the interference. The three important limitations for multichannel communication addressed are,

- the topology creation using wireless sensor nodes
- interference and contention on the wireless medium,
- bandwidth limitations and the half-duplex capability of the radios on the nodes

The reduced interference was achieved through multiple-sink topology, graph coloring scheduling algorithm etc. The discussion on multi channel communication challenges is based on the,

- Channel Overlaps
- Channel Switching
- Channel Coordination
- Channel Assignment

Different channel assignment algorithms like Fixed, Dynamic and Semi-dynamic channel assignment were discussed. Some channel assignment based protocol discussed in the literature is fixed channel assignment discussed by Wu et al (2008) which achieved the efficient data collection. Semi-dynamic channel assignment based communication protocol discussed by Incel et al (2011) achieved the reduced interference.

The coverage with connectivity properties in wireless sensor networks were addressed by Sahu & Gupta (2012). The solution for the coverage problem during the deployment of the sensor nodes is discussed in this literature. The strategy used for coverage problem was divided into three categories like force based, grid based and computational geometry based. In force-based and grid based strategies, the maximum coverage was achieved by using virtual repulsive and attractive forces. Due to this concept the sensors were forced to move away or towards each other. Voronoi diagram was used in computational geometry based strategy for achieving coverage.

Phung et al (2013) proposed the Reinforcement Learning based scheduling algorithm for route selection and transmission scheduling. The designed multichannel protocol addressed the problems of collision, idle listening, overhearing, deafness, hidden problems and maximizing the throughput. It was developed based on the Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) techniques. As the protocol was designed based on the combination of TDMA and FDMA techniques the author could achieve the collision-free communication. The failed transmission due to forwarding of the generated data packets to the sink also was eliminated by the coordinating the action of each node in each timeslot. The Reinforcement Learning algorithm was used for achieving the channel coordination among nodes. The appropriate channel and parent had been selected from the combined effect of medium access resolution and route selection algorithm.

This Thesis proposes Multichannel assignment and channel switching algorithm based multi-cluster network topology with static Sink (S) for achieving maximum data collection. The *Multi-cluster Multi-channel Monitoring (MMM) algorithm* proposed in this Chapter uses the fixed channel assignment algorithm and proper channel switching for achieving less interference communication.

3.3. MMM - TOPOLOGY CONSTRUCTION

Wireless Sensor Networks (WSNs) are traditionally developed by deploying various types of devices which are configured to act as source node, router node, sink node etc, and are randomly distributed over the monitored region. The topology creation and the topology maintenance are the key issues discussed in the literature.

The main objective of this Thesis is to develop the multi-cluster topology with maximum transmission coverage range and maximum data collection. The proposed topology includes various devices which are configured as Cluster Member (CM) or End Device (ED), Cluster Head (CH), Gateway node (GN), Sink (S) and Base Station (BS) or Coordinator (C). The constructed topology is analyzed by means of *IEEE 802.15.4 Wireless Personal Area Network (WPAN)* association procedure.

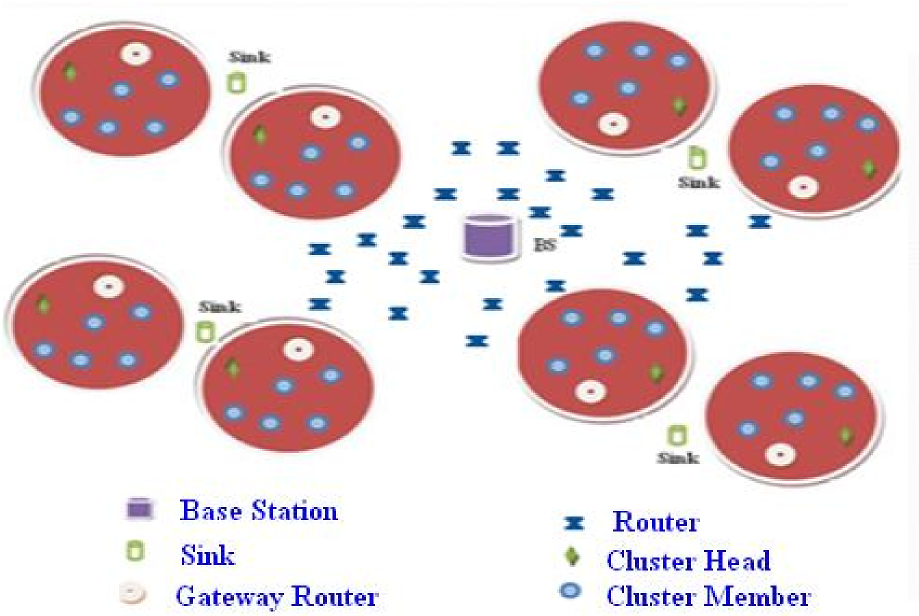

Figure 3.1 Cluster based Multi-Sink Topology (Kone et al 2010)

Generally topology control is divided into two parts,

- Topology construction
- Topology maintenance

In topology construction, the initial topology is either reduced constructed topology or random deployment of nodes. When the topology is in random manner, the administrator has no control over the design of the network; for example, in some location, nodes may be very densely deployed and very lightly deployed in some other locations. More number of redundant nodes are shown in the densely deployed location. This will increase the number of message collisions and will provide duplication of the same information from similarly located nodes. Thus, these issues can be avoided by constructing proper network topology.

This Thesis proposes the construction of cluster based multi-sink network topology to withdraw these issues. The proposed cluster based multi-sink topology is shown in Figure 3.1. This topology is constructed with different types of wireless sensor nodes such as eight clusters with eight CHs, eight GNs, four sink and one BS.

Depending on the routing algorithm the sensor nodes in the network start sensing, transmitting or forwarding the packets regularly. Thus the selected nodes in the route consume energy. Some nodes will deplete energy completely after sometime. In multi-hop network, the nodes that are closer to the sink or BS spend more energy due to more packet forwarding than other nodes which are far away from the sink or BS. Therefore, the network must restore the network topology periodically in order to get connectivity, coverage, etc.

There are many ways to perform topology construction such as clustering, creation of communication backbone, change of transmission range etc. This Thesis focuses to develop the topology based on clustering of nodes and maximum coverage range. The FLCS algorithm explained in Chapter 2 discusses the formation of clusters with maximum coverage range and proper selection of cluster head and the event-driven based multichannel communication proposed in this Chapter for network connectivity and network lifetime enhancement.

This Chapter discusses the smart grid equipment health monitoring application development based on multi channel communication for transmission of sensed event information from the end device or cluster member to sink node. The end devices in the proposed cluster based multi-sink topology regularly sense the information. These end devices are supposed to be connected to the electrical equipments which are to be monitored. If any fault or abnormality occurs in the equipment, it is identified by the end device and the identified fault or abnormality is considered as ‘event’. The sensed information is communicated to CH only when an event occurs. CHs aggregate the collected cluster member information and then communicate it to the sink through the GN. Finally the event information received by the sink is communicated to the BS through routers using proper routing protocol which is discussed in Chapter 4.

3.4. MULTICHANNEL COMMUNICATION

Multichannel communication algorithms and protocols have been developed to minimize the effects of interference and accordingly improve the performance of the network in wireless sensor networks requiring high bandwidth. The main objective of the multichannel algorithm is to provide collision-free transmission. In fact, it is difficult to achieve a collision-free channel assignment and transmission schedule since nodes must share information dynamically and be involved in the channel assignment or scheduling process. In such cases, the proposed Channel Assignment (CA) and Channel Switching mechanism are required. The main focus of the proposed multichannel algorithm called Multicluster Multichannel Monitoring (MMM) Algorithm is to improve the network throughput by enabling the less interference multichannel communication. Carrier Sense Multiple Access (CSMA), Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA) are some of the existing techniques to share the wireless medium which discussed in the literature for minimizing the effect of interference (Phung et al 2013).

3.4.1. MMM- Channel Assignment and Channel Switching Strategy

The fundamentals of the channel assignment strategies used in wireless ad hoc networks can help to design efficient multichannel based protocol in WSN because the research focus of the WSN is to share the challenges of the single radio wireless ad hoc network. The IEEE 802.15.4 is the protocol standard used for Low Rate Wireless Personnel Area Network (LR-WPAN) which is presented by Callaway et al (2002).

The IEEE 802.15.4 standard for LR-WPANs was published to define the protocol for low data-rate (250 kbps at 2.4 GHz), low-power, and low complexity short-range wireless communication devices. It provides beacon-enabled communication for real-time message exchange, allowing up to seven guaranteed time slot (GTS) allocations in the contention free period (CFP) of a super frame. Since the standard allows including the GTS allocation information only in four consecutive beacon frames, the maximum real-time message in a network is limited to the maximum number of GTS allocations. The standard generates the standard specific parameters such as beacon order (BO, defining the beacon interval), super frame order (SO, defining the super frame duration), and GTS information for the super frame structure to meet the real-time constraints of tens or hundreds of periodic real-time messages.

The IEEE 802.15.4 standard (Lee 2006) offers three different frequency bands which are *2.4GHz* for data rate of 250kbps, *915MHz* for 40kbps and *868MHz* for 20kbps. The 868MHz frequency band has one channel between 868.0MHz and 868.6MHz, 915MHz frequency band has10 channels between 902.0 MHz and 928.0MHz and 2.4GHZ has 16 channels between 2.4GHz and 2.48GHz which are shown in Figure 3.2.

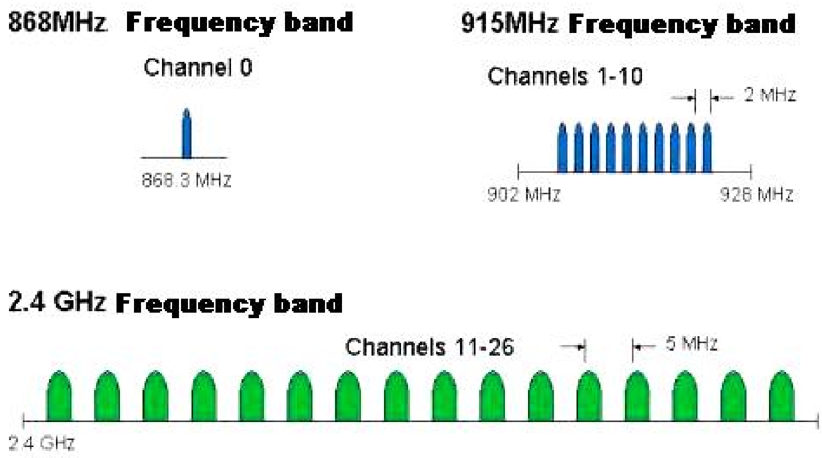

Figure 3.2 IEEE 802.15.4 Operating Channels (Lee 2006)

The proposed MMM uses the fixed channel assignment strategy for allocation of operating frequency band for CH, CM and Sink. The algorithm is developed and evaluated on evaluation board of XB24-ZB with an ATmega32U microcontroller and IEEE 802.15.4 compliant transceiver. In the cluster based multi-sink network shown in Figure 3.1, a fixed channel is allocated for CH node and ED or CM node for transmission and reception. Similarly, the sink and BS (or C) operate on another channel. The GN node is the only node which switches the channel between the channel of CH and sink. The main criterion of the proposed algorithm during the channel assignment phase is that 'Two adjacent Clusters should not be operated on the two adjacent channels'. For example if *Cluster1* is operated on *'Channel 11'*, *Cluster2* should not be assigned to operate on the next *'Channel 12'*. It means that any operating channel *other than 'Channel 12'* is allocated for *Cluster2*. This way of channel assignment strategy minimizes the effect of interference and decreases packet collisions. Hence this Thesis considers good link quality, since the link quality and interferences are indirectly proportional factors.

3.4.2. Channel Switching Algorithm

The MMM algorithm is developed for event-driven based applications. The source node in the cluster network senses the information continuously. When an event occurs, it immediately communicates the event information to the CH without delay since both CM and CH are operated on the same frequency band. The event information is transmitted to the BS through the GN and sink node. In this algorithm, the Sink and BS also are operated on the same operating channel. GN is the *gateway* node between CH and sink node which *switches the channel* between the operating channel of CH and operating channel of sink. The channel negotiation is done via Clear Channel Assessment (CCA) control packets. The MMM algorithm used for the multichannel communication is shown in Figure 3.3.

In MMM algorithm, initially CM and CH are operated on the same channel. Similarly Sink and BS are operated on the same channel but it is not the same as the previous one. GN stays in the control channel. The channel switching of GN is done in this Chapter by broadcasting the control packets, which is explained as follows,

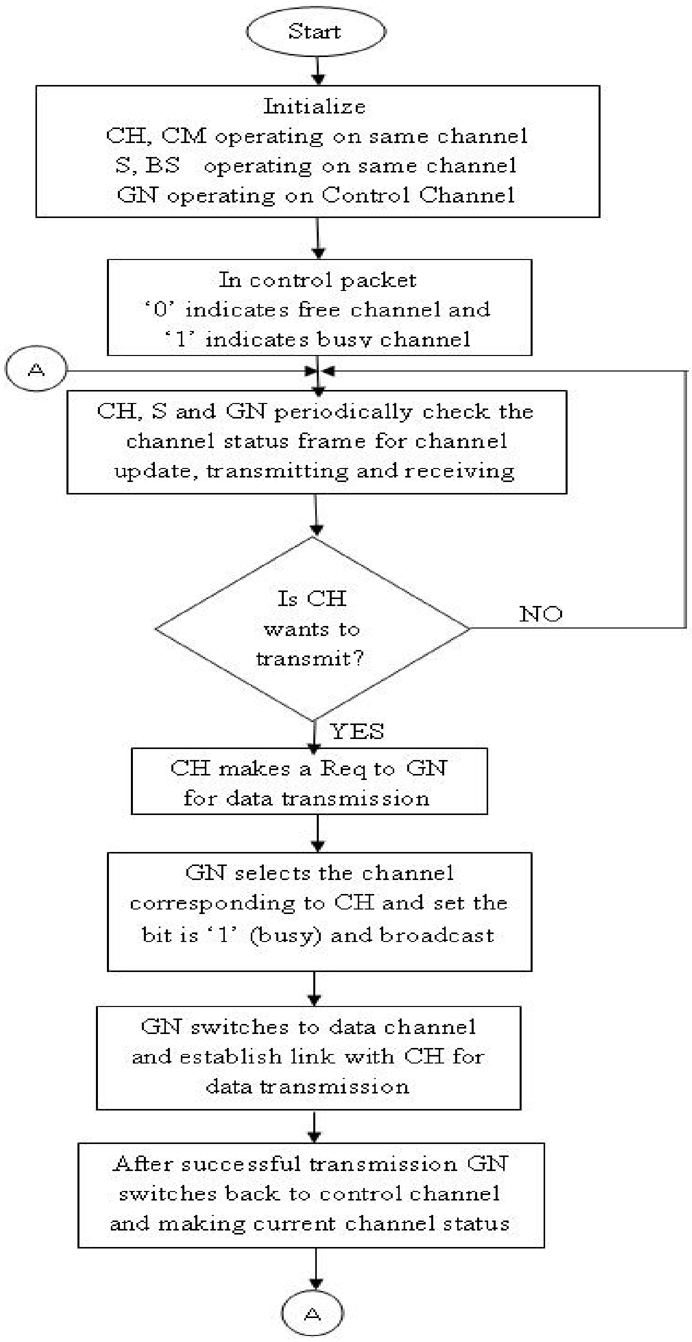

Figure 3.3 Algorithm for Channel Switching

- Communication between CM and CH:

  1. Initially the radio of CMs, CHs are in sleep mode and radio of GN and Sink are in low power listening mode.
  2. When an event occurs, it wakes up the radio of CM and CM sends the short preamble to wake up radio of CH then transmits event information to CH.
  3. After receiving the event information from CM, CH sends ACK to CM. Upon reception of ACK, CM radio goes back to sleep mode.

- Channel Switching: Communication between CH and Sink through GN:

  1. If CH wishes to transmit, it makes a channel request by sending control packet to GN. The CH sets the corresponding channel bit to ‘1’ in control packets before sending.
  2. After reception of control packet, GN switches from control channel to CH’s data channel if it is free and establishes a link for data and ACK transmission.
  3. When the control packet is received by the unintended nodes i.e. other than GN node, the selected channel is marked as busy channel in channel status table.
  4. The DATA and ACK are transmitted in the data channel. After transmission and reception of data and ACK packets node measures the RSSI for each channel and updates the Channel status table. Thus the loss of channel information problem is countered.

5. After successful transmission of DATA and ACK, the GN node again switches to the control channel.

6. Upon reception of ACK from the GN, the radio of CH goes back to sleep mode.

In similar way, the event information is transmitted between GN and Sink. After completion of the DATA and ACK transmission GN again switches back to the control channel.

3.4.3. Control Frame Format for MMM

The control frame format for multichannel MAC is shown Figure 3.4. This control frame is used as control packet in MMM algorithm for establishing the communication between CH, GN and Sink. This format consists of MAC header, MAC payload and MAC footer. The MAC header has Frame control, Data sequence number and information of the destination. The Frame control field indicates the type of the frame, pending frame and acknowledge request. Data sequence number is the serial number of the data. The address of the destination is indicated in the Destination Address information. The MAC payload has two fields such as command type and command payload. The type of the commands like Association Request, Association Response, Disassociation Notification and Data request are indicated in the command type field. It is indicated with one octet.

The command payload in the MAC payload field is the variable length field used. This Thesis uses the command payload field for controlling the channel activity and channel switching of GN. Among 16 channels of IEEE 802.15.4 the MMM algorithm uses only 8 channels from ‘Channel 14’ to ‘Channel 21’. This field is represented with two octets. The first octet is used to represent the channel status. Each bit in this field indicates the status of each channel. If it is '0', the corresponding channel is 'free' channel and if it is '1', the corresponding channel is 'busy' channel.

The second octet is used to represent the criticality of the event. The level of criticality of the event is represented by using 01H to 0FH, in which 01H indicates the less critical event and FFH indicates the more critical event. The level of criticality of the event is computed from the probability which is discussed in Chapter 2. When any two GN nodes are competing to establish a link with sink node, the sink node establishes the link with one GN who is having more critical event. Thus the link is established based on the priority. The highest priority is given to the node having more critical event and lowest priority is given to the node having less critical event. Like Cyclic Redundancy Check (CRC) the Frame check sequence is used in the MAC footer which is the last field with the length of two octets.

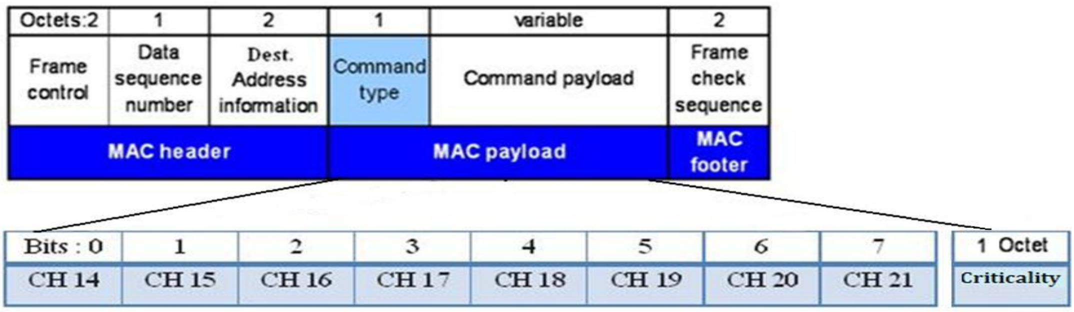

Figure 3.4 Control/Command Frame Format

3.4.4. Short Preamble

The Figure 3.5 shows the short preamble which is sent by CM to wakeup CH when an event occurs. The CM first sends short preamble to CH then it transmits data. Upon reception of preambles, the CH wakes up and receives data. After reception of data CH sends ACK to CM. Upon reception of ACK the radio of CM node goes to sleep mode. This way of communication completely avoids the energy consumption due to listening, overhearing etc. Thus, MMM algorithm is the energy efficient algorithm.

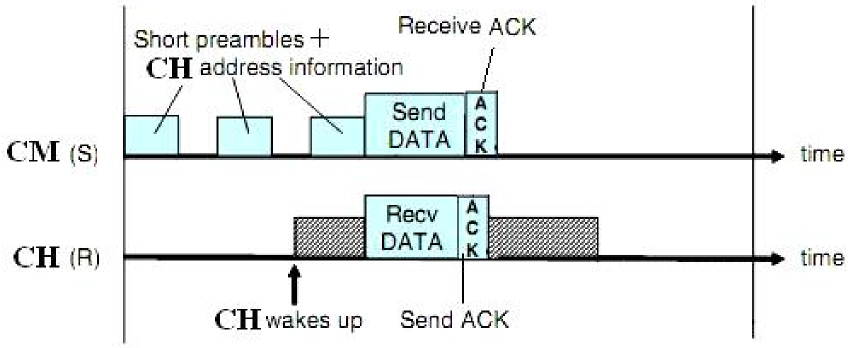

Figure 3.5 Short Preambles to Wakeup CH

3.5. EXPERIMENTAL TESTBED FOR MMM

The experimental testbed shown in the Figure 3.6 is developed using Leonardo evaluation board with XB24-ZB and ATmega32U4 microcontroller and IEEE 802.15.4 compliant XBee transceiver. The supply voltage required for the evaluation board is 5V. It has 12 analog input ports and a clock speed of 16MHz. The Flash Memory of ATmega32u4 is 32 KB in which 4 KB is used by boot loader, SRAM of 2.5 KB and EEPROM of 1KB. The specification used for the experimental testbed is shown in Table 3.1.

The testbed is constructed with XBEE transceiver (XBee Series 2 data sheet information) having operating frequency of 2.4GHz. The testbed consists of seven motes (nodes) with XBEE transceiver. These motes are configured as one CH, and two EDs on channel 14, two Sinks and BS on channel 20, one GN initially operating on control channel 21.

Table 3.1 Experimental Testbed Specification

Types	Specification
Processor	ATmega32u4
Flash Memory	32 KB
Analog Input	12 pins
Clock Speed	16 MHz
ZIGBEE	XBee series2 transceiver
Operation Frequency	2.4 GHz
Data Rate	250Kbps
Indoor Range	up to 40 m
Outdoor Range	up to 120 m

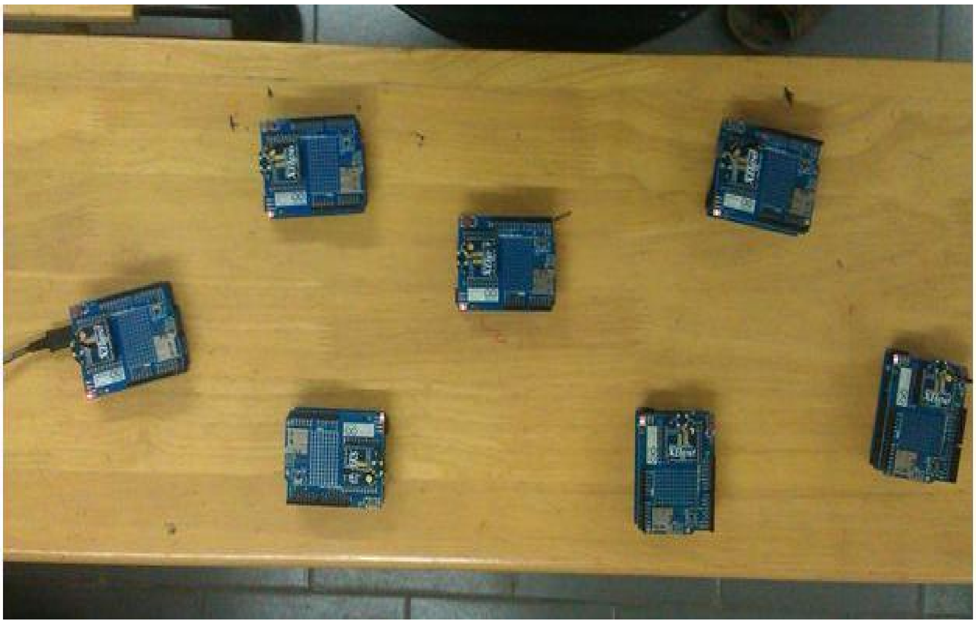

Figure 3.6 Experiment on Networking with XBEE Series2

The CH and ED of the testbed is configured with operating channel of *'Channel 14'* and sink and BS or coordinator are configured with operating channel of *'Channel 20'* The Gateway node is initially configured with control channel of *'Channel 21'*, and it switches the channel between *'Channel 14'* and *'Channel 20'* depending on the channel request.

The channel assigned to CH, S and C is based on the fixed channel assignment. The semi dynamic channel assignment is used for assigning three operating channels to GN. This means that the GN node has the capability of switching between operating channels. The CH makes a channel request to GN only when the event occurs. The CH either communicates to the GN or to the C, depending on the criticality of the event and the availability of the GN channel. The occurred event is less critical or medium critical, the CH waits for the channel coordination with GN and then transmits the event information. Suppose the event is more critical and the channel of GN is busy, then the CH switches to the operating channel of 'S' and establishes the communication directly with the sink.

The analysis of the channel switching is done through Perytons, a standard Network Protocol Analyzer, ver 4.0. It is the network analyzer capable of simultaneously capturing data from multiple channels supports different standard protocols such as zigbee, 6LoWPAN, IEEE 802.15.4 etc. The 802.15.4 defines 16 possible communication channels in the 2.4 GHz ISM band. This analyzer captures all the IEEE 802.15.4 traffic in the 2.4GHz band simultaneously.

The channel switching analysis of 'GN' between Channel 14 having operating frequency of 2.415GHz and Channel 20 having operating frequency of 2.445GHz is shown in Figure 3.7 and Figure 3.8 respectively. All the nodes in the network which are operating on the same channel and the link between nodes are analyzed through the network-view of Perytons analyzer. The node with pink colour shows that the node is transmitting packets; yellow node indicates that the node is waiting for the link. The link with violet line indicates that the communication link is to be established, link with green line indicates that the data is transmitted. The yellow node with link indicates that the node is participating in the network communication which means the status of the node is ‘active’. The yellow node without a link or connectivity indicates that the node is ‘inactive’ state; it means that the node is in sleep state.

The network view of Channel 14 shown in Figure 3.7 has four nodes, in which three nodes are participating in the communication and one node is in inactive state. The node with node-id ‘0013A200406FBE63’, ‘0013A200407947CE’, ‘0013A200406FD769’ and ‘0013A200406FEEF3’ are configured as GN1, Sink1, CH1 and CM. The CM node transmits the data to the CH1 node. The link with pink colour shows the data transmission between CM and CH1. Once CH1 receives the data from the CM it makes a channel request to GN1. The link is established between CH1 and GN1 after the reception of channel request from CH1 by GN1. The green line indicates the link establishment. The node with ID ‘0013A200406FBE63’ act as a GN node during channel 14, it establishes a link to the CH1.

Similarly, Figure 3.8 shows the network view for Channel 20. Once GN1 node receives the data from CH1, it would be communicated to the sink node. Thus GN1 node switches the channel from ‘Channel 14’ to ‘Channel 20’ and establishes the communication. The pink nodes with green link clearly indicate this communication establishment of GN1 to Sink1 during Channel 20.

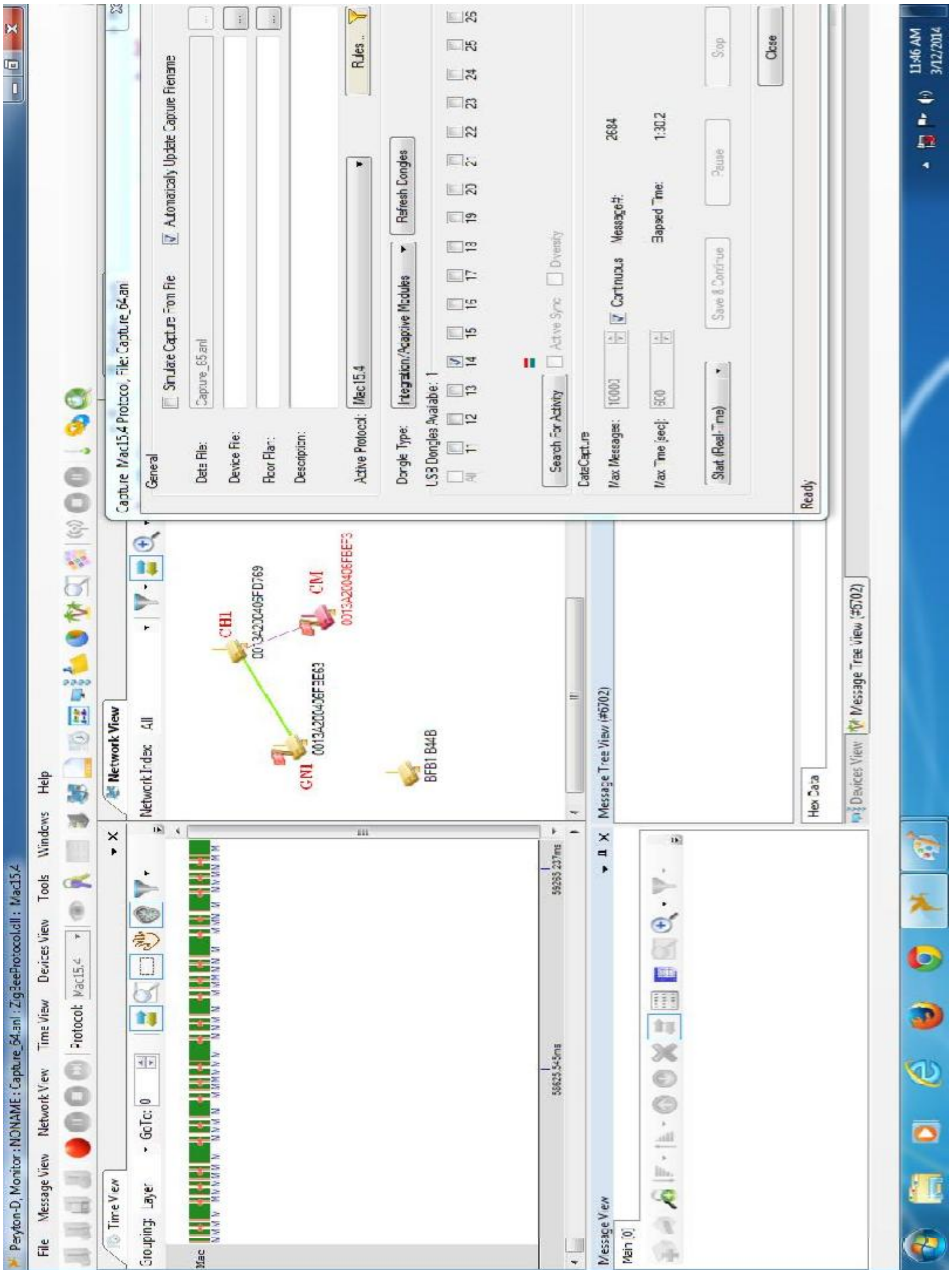

Figure 3.7 Channel Switching: Perytons Analyzer snapshot - Channel 14 (2.415GHz)

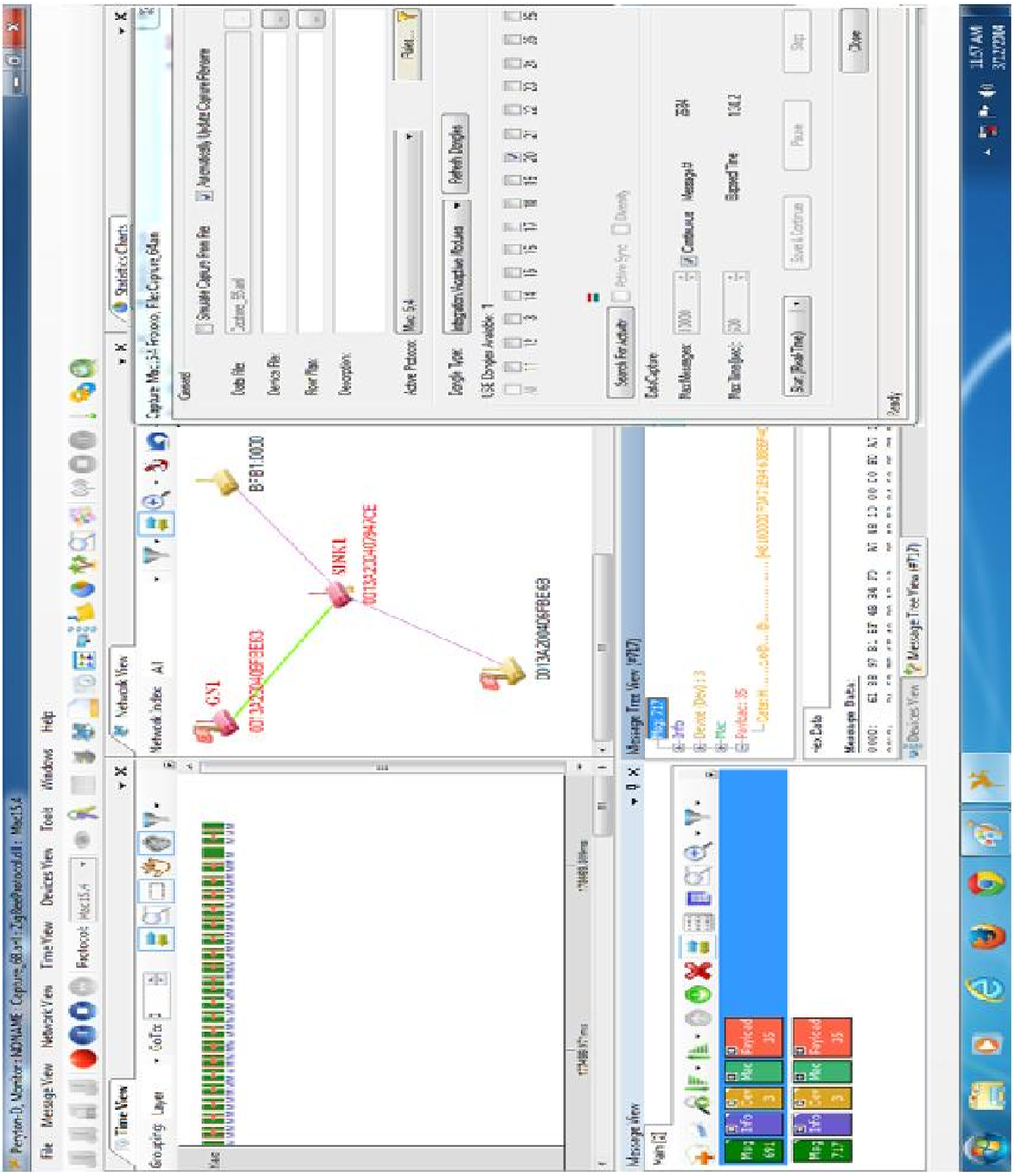

Figure 3.8 Channel Switching: Perytons Analyzer snapshot – Channel 20 (2.445GHz)

The active channel analysis of Channel 14 and Channel 20 are shown in Figure 3.9 and Figure 3.10 respectively. From the active channel analysis the number of packets transmitted during the Channel 14 is 19,880 and during Channel 20 is 2,297. This shows that packet transmission during Channel 14 is higher than Channel 20.

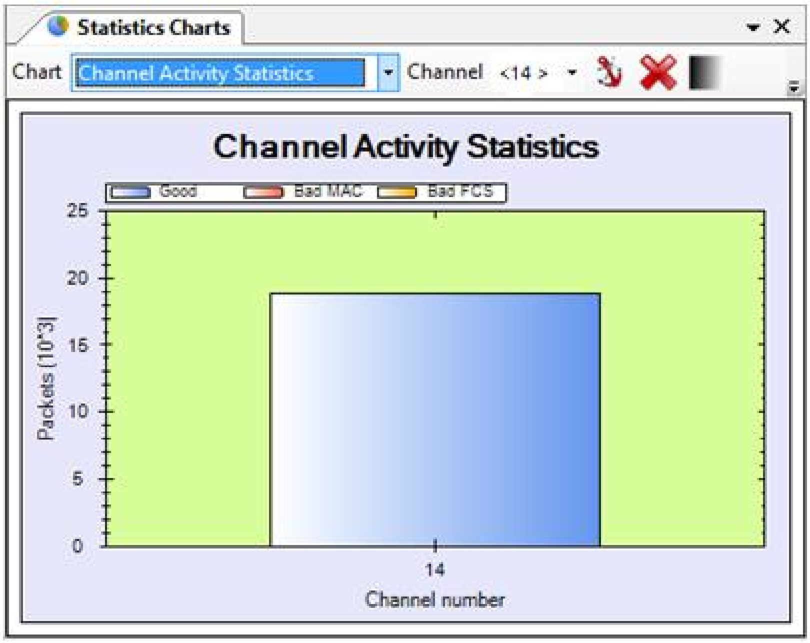

Figure 3.9 Active Channel Analysis (Channel 14)

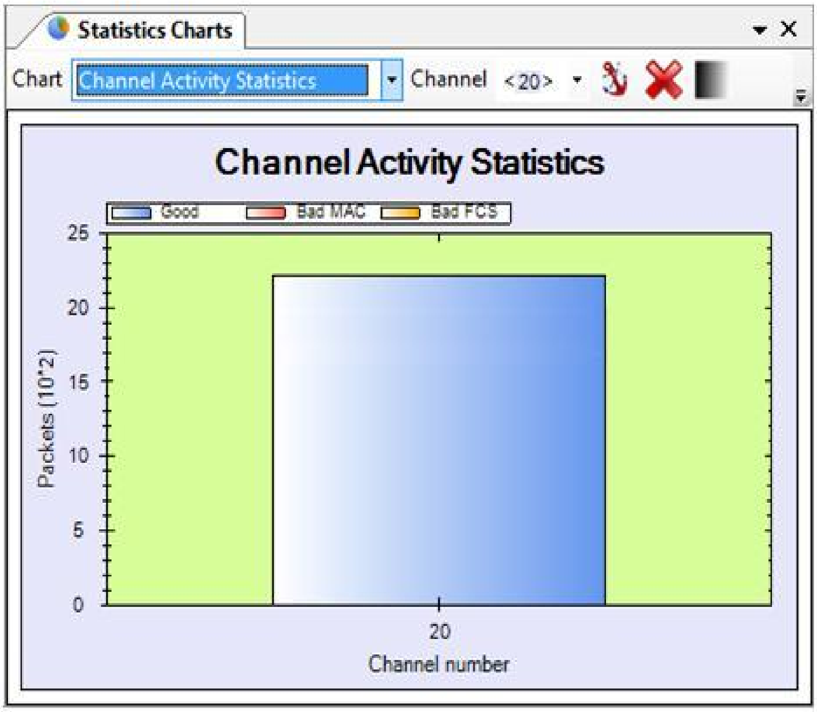

Figure 3.10 Active Channel Analysis (Channel 20)

3.6. PERFORMANCE ANALYSIS

3.6.1. Throughput Analysis for Varying Number of Channels

Figure 3.11 shows the throughput of the Multicluster Multichannel Monitoring (MMM) Algorithm. The throughput of MMM is compared with Min-Max and single channel algorithm by configuring the nodes with 8 channels. From the result, it can be observed that the MMM always exhibits better performance than the Min-Max and single channel, particularly for four and more channels. The MMM has achieved 9% more throughput than Min-Max and 38% more throughput than single channel. The throughput of the simulated MMM is higher than single channel and experimental MMM. This performance improvement is obtained because of fixed channel assignment with channel switching scheduled in MMM. When the number of channel is less, MMM shows a small improvement in performance of the obtained throughput as compared to Min-Max. As the number of operating channels increases, the proposed algorithm shows a drastic performance improvement.

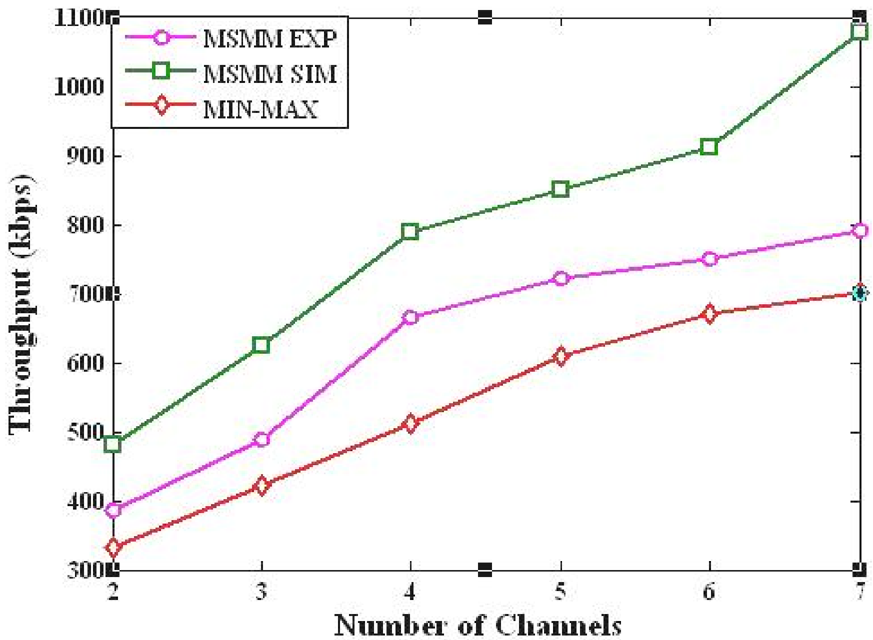

Figure 3.11 Throughput Increase with Number of Channels

3.6.2. Impact of Increase in Number of Channel on Packet Delay

Figure 3.12 and Figure 3.13 show the packet delay for different data rates with 4 channels and 8 channels respectively. Figure 3.12 shows that the maximum delay induced for data rate of 200 kbps using 4 operating channels, under Min-Max method is 0.361 seconds while that under MMM is only 0.314 seconds (Experimental MMM), 0.265 seconds (Simulated MMM). The experimental MMM has a packet delay of 0.063sec higher than simulated MMM. As compared to single channel and Min-Max, the MMM algorithm has achieved 39% and 17% less delay.

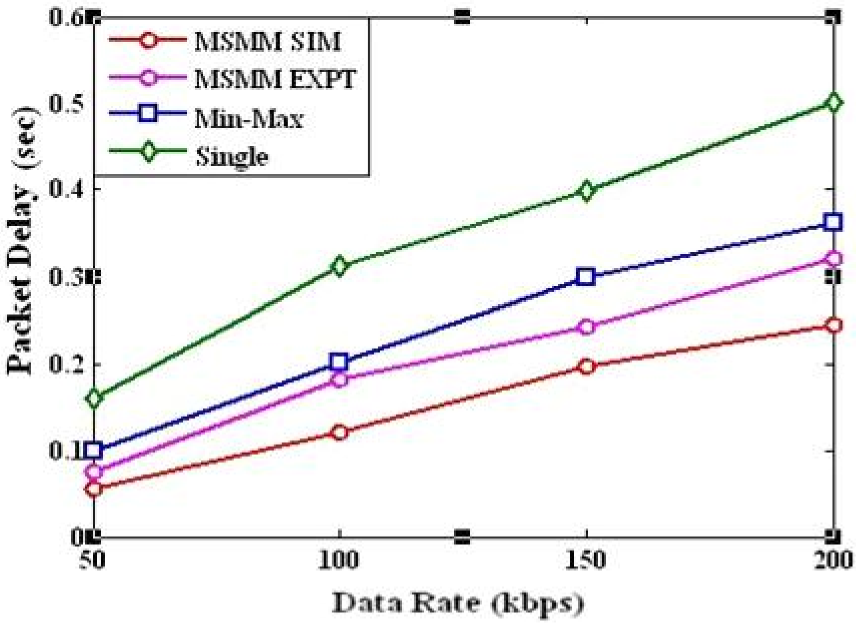

Figure 3.12 Multi Channel Decreases Delay: Case Study 4 Channels

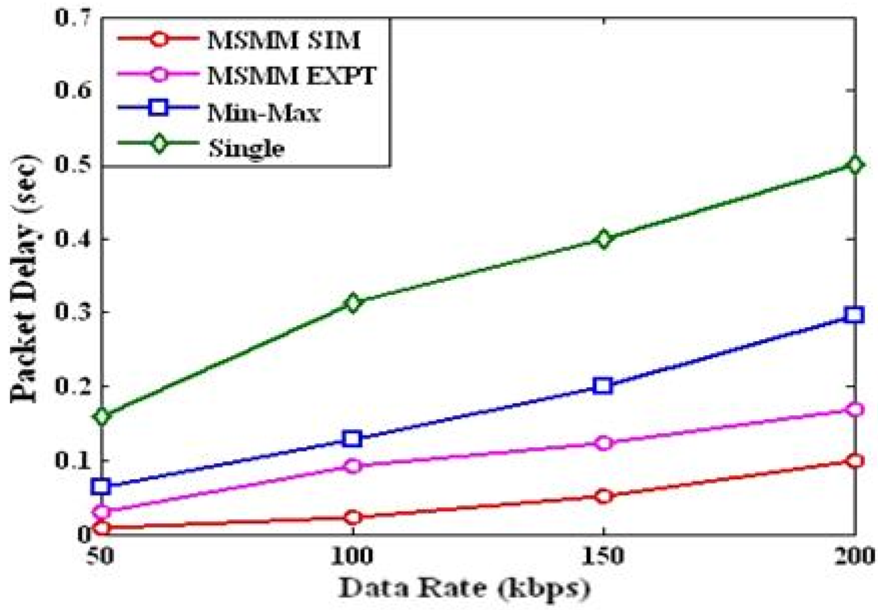

Figure 3.13 Multi Channel Decreases Delay: Case Study 8 channels

From Figure 3.13, it has been observed that for a network operating with 8 channels the delay per packet is 0.295 seconds under Min-Max method , 0.169 seconds under experimental MMM algorithm and 0.110 seconds under simulated MMM algorithm for the data rate of 200kbps. The results show that the proposed MMM of channel allocation is more effective in terms of packet latency by distributing the load equally among the operating channels. From the result it is proved that the increase the number of operating channels will show an improved timeliness. Timeliness is one of the important criterion for any critical event handling system.

3.6.3. Traffic Pattern based Data Collection Analysis

The Constant Bit Rate (CBR) traffic type is used for network connections that transfer traffic or packets at a constant bit rate, where there is an inherent dependence on time synchronization between the traffic source and destination. CBR is adaptable for any type of packet for which the end-devices require predictable response time and continuously available fixed range of bandwidth for the life-time of the connection.

Poisson traffic model follows the Poisson probability distribution which expresses the probability of the given number of event occurring in a fixed or some specified interval of time. Due to this reason, the Poisson traffic model is more suitable for event based traffic than the continuous monitoring.

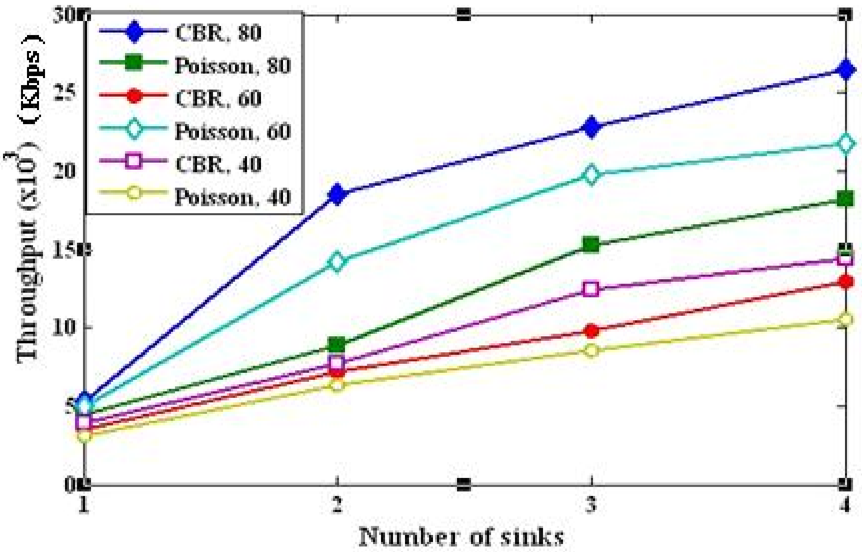

Figure 3.14 Increase in Throughput with Increase in Number of Sinks

The data collected by the multiple sink for various traffic patterns such as CBR and Poisson are shown in Figure 3.14. The throughput analysis of the cluster based multi sink topology has been done for different packet sizes such as 40 bytes, 60 bytes and 80 bytes. The throughput drastically increases with the number of sinks in all cases. There is no big difference in data collection when the number of sink is ‘1’. It is comparatively less data collection than multiple sinks, since the packet collisions occur in single sink data collection is high. Average throughput is increased in both traffic patterns as the number of sinks and the packet size increase. The maximum data collection is obtained when the number of sink is ‘4’ and the packet size is equal to ‘80’. When the traffic pattern is taken into account, CBR works well for continuous monitoring applications and Poisson traffic pattern is more suitable for event monitoring applications.

3.7. CONCLUSION

The main contribution of this Chapter includes:

- The cluster based multi-sink topology and MMM algorithm are designed in order to meet the objectives of balancing throughput and timeliness.
- A multi channel algorithm that is used to relay sensor information from the field nodes to designated coordinator nodes has been designed.
- The algorithm has the features of load balancing by distributing the traffic among multiple channels in the network, thereby maximizing throughput.
- The scalability has been achieved through MMM algorithm because of using multiple sink. The other factors like throughput, packet delay is also been analyzed.
- From the results it could be inferred that the delay incurred for various data rates by using eight channels network is less compared to the delay for four channels.

The deployment of the proposed cluster based multi-sink network is developed with maximum coverage of the transmission range. MMM discussed in this Chapter reduces the end to end delay and increases the network throughput. Because of the proposed channel assignment and channel switching scheduled algorithm, the less interference transmission of the packet can be achieved. This Chapter discusses the deployment of the cluster based multi-sink network, allocation of the channel to node and channel switching. This can be applied for Smart Grid monitoring of System Health.

The cluster based topology with multichannel assignment has been developed in this Chapter which transmits the event information from the end device or cluster member to the sink. But, when event occurs, the event information is required to be transmitted to the Base Station(BS). Thus, the sink node requires an efficient routing protocol to forward the event information to the BS. This Chapter does not specify any routing protocol for data transmission. The energy efficient and load balanced multipath routing protocol based on Modified Intelligent Water Drop optimization algorithm is disscussed in the next Chapter.