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Modified Intra-Cluster Grouping Scheme using Beamforming Technique in Standard IEEE 802.15.4 Wireless Sensor Network

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Abstract: IEEE 802.15.4 is a WPAN (Wireless Personal Area Network) standard which is designed for short range communication. Wireless sensor networks use this standard for its communication. Most of these networks are battery operated. So, power resource has to be properly utilized to balance network performance. This standard follows blind random backoff contention mechanism which turns off the transceiver when it does not have data to transmit. Such, a design creates Hidden Node Collision (HNC) in a network which degrades network performance it terms of throughput, packet delay and power consumption. In this study, a new technique has been proposed in grouping strategy to mitigate the Hidden Node Collision (HNC) problem. Additionally, it introduces beamforming technique to conserve energy in the network. Simulations illustrates that proposed research not only avoids HNC problem but also outperforms IEEE 802.15.4 standard and previous grouping strategies.

Key words: Wireless sensor networks, network performance, backoff, hidden node collision, beamforming

INTRODUCTION

Wireless Sensor Networks (WSN) are one of the eminent technologies in the recent years. It is the low powered and low power consumption devices which have central sink to collect data from nodes (Akyildiz *et al.*, 2002). WSN are widely deployed in health monitoring, military, industry, etc. Reducing power consumption of wireless sensor network is a major concern; it can be achieved by decreasing number of retransmissions. Retransmission occurs when hidden node situation happens. When two nodes want to transmit data to a same node which are visible to each other causes hidden node collision. Even though the coordinator covers the entire range, HNC occurs (IEEE Standards Association, 2003) (Fig. 1).

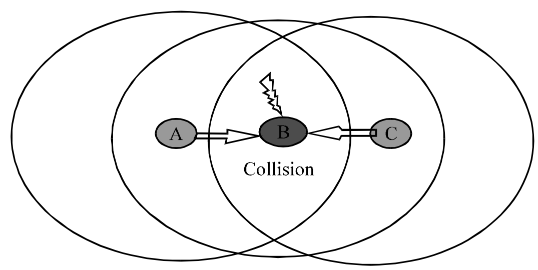

Fig. 1: Hidden node collision

Previous researches have worked on reducing hidden node collision but only some of them have worked on avoiding HNC. In this study, proposed research also focuses on avoiding HNC problem. HNC problem can be avoided by grouping nodes in a cluster region such that nodes in a group are not hidden to each other. In previous grouping strategies, when a coordinator detects hidden node collision it starts the polling process to collect hidden node information. All the nodes report their hidden node information to coordinator (Hwang *et al.*, 2005). Coordinator separates the nodes into groups such that nodes in a group are not hidden to each other. Then, they are allowed to transmit their data in a scheduled time period. Nodes in a group are allowed to contend for time slots in scheduled time of that particular group.

In IEEE 802.15.4 nodes stay in idle state when they do not have packets to transmit (IEEE Standards Association, 2006; ZigBee Alliance, 2006). So, if nodes are in idle state this polling mechanism results in unreliable collection of hidden node information. Finally, grouping becomes unreliable and causes HNC problem. In this proposed grouping technique,

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coordinator sends a beacon signal to all the nodes in its region to wake up the nodes during the grouping process. Moreover, this study worked on reducing energy wastage in all cluster zones while grouping a new node in a network through technique (Godara, 1997). This proposed technique finishes the grouping mechanism with O(n) complexity where n is the number of nodes.

Literature review: Many of the researches have worked on finding the solution to reduce hidden node problem in wireless sensor networks (Fullmer and Garcia-Luna-Aceves, 1997). Those researches have been described here:

Busy tone multiple access: In this approach, each node requires one additional channel to mitigate HNC (Wu and Li, 1987; Haas and Deng, 2002). More specifically a busy tone message is transmitted to nearby nodes through a narrow channel. Nodes which receive this message stop transmission during that time to avoid HNC. Hence, it consumes additional power for extra channel which is not suitable for ZigBee networks.

RTS/CTS mechanism: Request to Send/clear to Send (RTS/CTS) mechanism avoids HNC (Xu *et al*., 2002). Sender sends short RTS message to reserve channel bandwidth. Receiver replies with CTS to confirm the reservation of channel bandwidth for transmission. ZigBee superframe size is small therefore, it is difficult to send RTS/CTS before data transmission (IEEE Standards Association, 2003; Zhai and Fang, 2006).

Power control: Several researches have focused on power control scheme to reduce HNC problem. Every node changes their transmission power to sense different carrier frequency ranges and interference (Jung and Vaidya, 2002). Power range of ZigBee is already low, so decreasing its power causes unreliable communication. Solving HNC problem through power control mechanism is not suitable (Deng *et al*., 2004).

Node grouping: Node grouping is an optimum technique to avoid HNC problem. Nodes are grouped according to their hidden node information graph. These groups are scheduled in non-overlapping time periods to avoid collision. It is a reactive grouping process, when coordinator detects a hidden node collision in its range it starts collecting hidden node information from all the nodes by polling process. Nodes report their hidden node information to coordinator. Coordinator in turn separate nodes into different groups according to their constructed hidden node graph (Hwang *et al*., 2005). However, this hidden node information collection is inefficient and unreliable. As new node arrives, it starts collecting hidden node information and regroups all the nodes according to collected information. Complexity is high because it needs $O(N^2)$ messages to collect information. But in proposed approach HNC problem is solved with O(N) complexity.

HNAMe: HNAMe is also a node grouping technique to solve HNC problem (Koubaa *et al*., 2007). It is a node initiated proactive technique where a new coming node sends a group join request to coordinator with special address by broadcasting. Neighbor nodes hear this message and sends notification to coordinator by broadcasting. New node hears this and builds a relationship table. Then, it sends neighbor report to coordinator. With neighbour report coordinator groups the new node. This technique solves HNC with O(N) complexity. In sensor networks nodes may stay in sleep mode to save power. So, if nodes are in sleep mode, they may not overhear information. As a result, hidden information collection becomes unreliable. But proposed approach solves HNC in a reliable way.

MATERIALS AND METHODS

Modified Intra-Cluster Grouping Scheme (MIC-GS): It is an efficient and reliable grouping scheme initiated by node. Coordinator sends beacon signal to all the nodes in its coverage area to wakeup nodes. Thereby, it meets a reliable information collection process. It consists of four phases, hidden node information collection phase, grouping phase, group access period allocation and results notification phase (Table 1).

Hidden node information collection phase

Step 1 (Group join request): Consider that each new arriving node (e.g., node NN) wants to avoid hidden node collision. Node NN sends group join request to coordinator. Coordinator checks time slots whether any node occupies for next two superframes. Then, it sends acknowledgement to new node (Fig. 2).

Step 2 (Beacon notification): Coordinator sends Beacon-II to all nodes. Beacon-II contains two important messages:

- Coordinator instructs all existing nodes to receive beacon from new node NN on a particular time

Table 1: Hidden node information table of New Node (NN)

Non-hidden nodes	Hidden nodes
N1, N2, N3, N4	N5, N6, N7

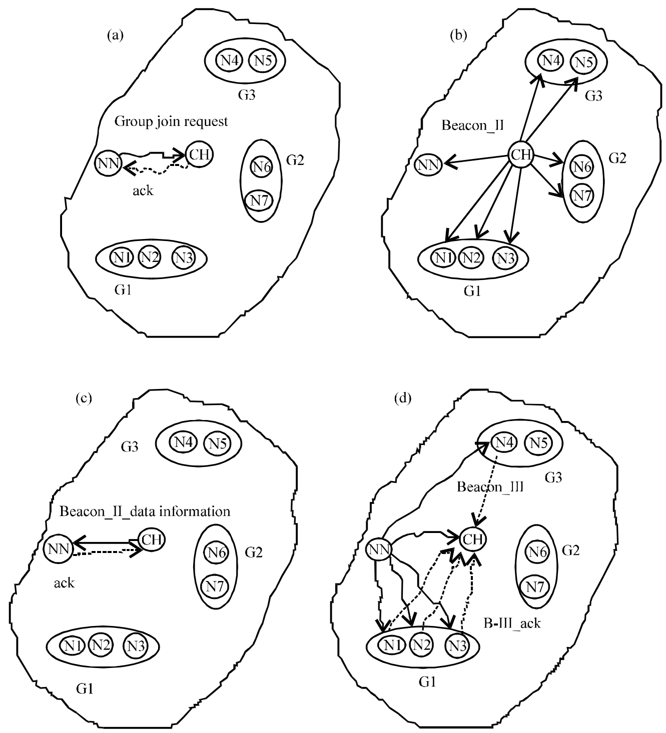

Fig. 2: Network scenario; a) Group join request; b) Beacon-II notification; c) Beacon-II_data information notification and d) Neighbour notification

- The time, when node NN broadcast Beacon-III is filled in Beacon-II

Then, coordinator sends B-II_data information signal to node NN and at the same time node NN needs to acknowledge it. B-II_data information carries necessary information to be broadcasted and the time when node NN can transmit Beacon-III. After node NN receives B-II_data information without error it sends acknowledge signal back to coordinator.

Step 3 (Neighbor notification): Node NN broadcast the Beacon-III and triggers the timer. Timer is used to calculate waiting time of the coordinator which collects responses (Beacon-II ack) from all nodes. Beacon-III is like the normal beacon but broadcaster is new node NN and the receiving nodes sends acknowledge signal to coordinator.

Since, Beacon-III is broadcasted by node NN, all the nodes in the NN's transmission range will hear the beacon. Thus, coordinator knows that node which sends Beacon-IIIack is the neighbor node of NN. Therefore, now coordinator constructs hidden node information table of node NN.

Grouping phase: From the previous study, it is known that when a new node arrives hidden node information table changes. Once the table formed, coordinator starts group assigning process to the new node. Group should be assigned in such a way that does not change the nodes which have been assigned to other groups which creates unwanted control messages inside the network.

In group assigning process, nodes which have relations in the hidden information table can't be assigned to the same group. In a group, all the nodes are visible to each other (Kwon *et al*., 2009). Thereby, it avoids HNC problem because there won't be any hidden situation in any node.

Grouping algorithm:

```
Input: Given hidden node information table (H) of the new coming nodes
       (T) and the number of the existed group K;
Output: The group sets Gi of the new coming node allocates;
   Group set G = {G1, G2, ..., Gg}, g≤K;
   while |T|>0 do
      Pick a node X having the maximal number of hidden
      nodes from T;
      if no existed group then
      K = 1;
      construct group set Gk = {X};
      T = T-{X};
      return Gk; s
      else
         while |G|>0 do
         pick a group G' having the minimal number of
        nodes from G;
            if node X has no edge to any nodes in
            G'then
```

```
            G' = G' + {X}; // join into group G'
            T = T - {X};
            Return G';
            else
            G = G- G';
           end if
         end
          K++;
          T = T-{X};
          construct group set Gk = {X};
          return Gk;
      end
  end
```

If too many groups assigned to a network, bandwidth resource allocation will not be acceptable. Therefore, number of nodes in a group and number of groups in a network are to be balanced.

In proposed research, a grouping algorithm is developed to balance load and number of nodes in a group. Let H denote the set of hidden node information table of new coming nodes, T is the set of new coming nodes and K is the set of existed groups.

Algorithm first picks a node with maximum hidden nodes and checks whether there are existed groups. If no groups exist then it assigns new node to a new group. If there are existed groups then the node will be assigned to a group with minimum number of nodes. At last group accept information will be sent to that particular node, in order to inform the node about its group join result by the coordinator. Figure 3 shows the assigned group to new node NN. This modified intra-cluster grouping scheme maintains a maximum of 9 groups inside the cluster region to avoid HNC problem.

Group access period allocation: Nodes in a cluster region are separated into groups to avoid HNC problem. Group access period of one group is influenced not only the number of nodes in a group but also the average backoff interval (I_b) and it is found that probability frames successfully transmitted can also influence average backoff interval. Hence, average backoff interval is constructed as follows.

Assume that the active period excluding the minimal CAP and the CFP is L (in UBP) and there are total M nodes which can be separated into K groups. $Group_i$ has N_i devices, access period is T_{Gi} and the probability of a frame successfully transmitted is P_i, for i = 1, 2, ..., k. Let w_j be the size of the Contention Window (CW) for a frame transmission in the jth backoff retries and the basic CW unit is UBP:

$$T_{Gi}(N_i) = \frac{I_{bi}(N_i)\times N_i}{\sum_{j=0}^{3} I_{bi}(N_i)\times N_i}\times L \quad (1)$$

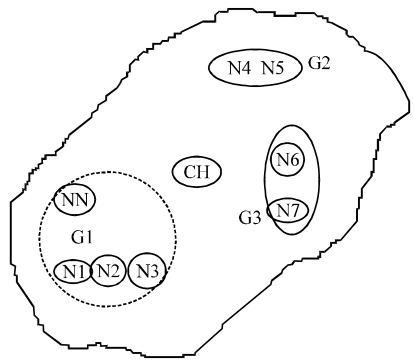

Fig. 3: Group assignment

Where:

$$I_{bi}(N_i) = \sum_{j=0}^{3} P_i\{1-P_i\}\, j\left[I_{j,s} + \sum_{x=0}^{j-1} I_{j,f}\right] \quad (2)$$

In the IEEE 802.15.4 specification, it is find out that retry counts are three times per frame. In the jth retry, the CW size will be $w_j = \min(2j\times w_0, 25)$ for j = 1, 2 and 3, where w_0 = 8. Let the average time duration of successful and failed channel accesses in the jth retry be $I_{j,s}$ and $I_{j,f}$. There are two times of successful Clear Channel Assessment (CCA) operations in a successful channel access. If one of the CCAs is not executed successfully, the channel access for this transmission is failed:

$$I_{j,s} = \frac{W_j}{2} + 2T_{CCA} \quad (3)$$

$$I_{j,f} = \frac{W_j}{2} + \frac{3T_{CCA}}{2} \quad (4)$$

$$P_i = (e^{-\lambda})^{N_i} \quad (5)$$

Where:

N_i = The number of total nodes in group
i and λ = The frame arrival rate in the system

Since, it needs to balance the transmission opportunity of all nodes, let each group has the same transmission times and let each node has the same probability of transmission. And the sum of group access period is:

$$TG1+TG2+TG3+....+TGk = L \quad (6)$$

From Fig. 4, it is noticed that access period of one group is not linearly proportional to the number of nodes in it.

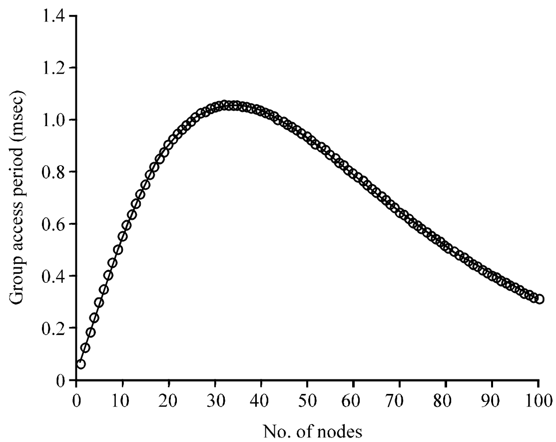

Fig. 4: Group access period

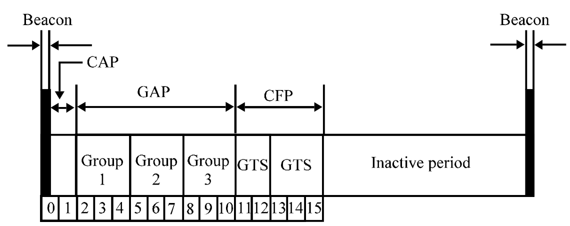

Fig. 5: Superframe structure

Results notification phase: In this phase, new node NN is informed about its group by the coordinator. Therefore, node NN can contend to transmit its data in a particular group access period.

An example superframe structure of IEEE 802.15.4 standard with grouping scheme is shown in Fig. 5. GAP (Group Access Period) is divided into subperiods (Lee *et al*., 2009). Each group has its own subperiod; subperiod is like guaranteed time slot description as in IEEE 802.15.4 standard.

Energy conservation

Energy wastage: In the existing research, during the node joining process energy wastage is high. This is due to the broadcast nature of wireless medium. When new coming node sends group join request, it reaches the entire neighbour cluster zones. Therefore, all the coordinators which receive this message, block the overall transmissions for a while to perform further processing of new coming node in their cluster region according to the Fig. 6.

But this new node will be joined to a cluster based on the response of a particular coordinator. This leads to wastage of power in the neighbour cluster zones.

Beamforming technique: In this study, beamforming technique has been proposed to conserve energy in the

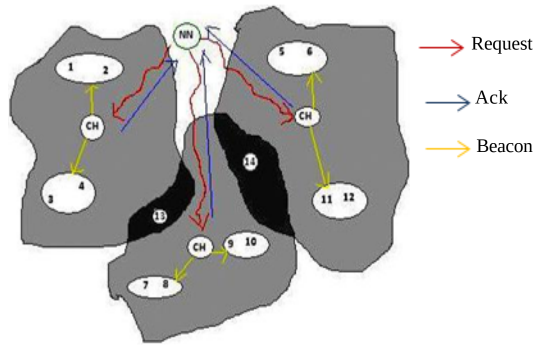

Fig. 6: Broadcast signal

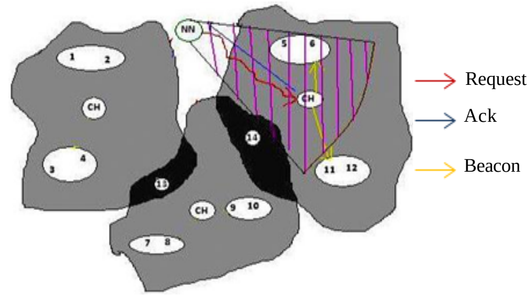

Fig. 7: Beamforming technique

network (Godara, 1997; Yang *et al*., 2005; Nilsson, 2009). In beamforming technique new node first scans in 360° to check the available coordinators with its beacon signal. Every coordinator which senses this beacon signal acknowledges to the new node. Acknowledgement message contains number of nodes and the number of groups in it. New node calculates the weight of the individual coordinator according to the received message. This new node then steers it antenna towards the particular coordinator with maximum weight to start the node grouping process. Figure 7 shows beamforming technique in a network.

Thus, in beamforming technique, only a particular cluster zone starts the group assignment process for new coming node. Therefore, energy wastage in rest of the non-participating cluster zones is removed. This increases the overall performance of a network.

Simulation and parameter

Simulation scenario: This study implements the proposed technique in a network simulation tool OPNET to analyses network performance in terms of delay, throughput, load capacity, etc. The network scenario consists of 100 mobile nodes along with coordinators and routers to perform simulation. Figure 8 shows the network model of the developed scenario. The standard ZigBee stack of every node is modified with proposed technique to analyses the results. Figure 9 shows the node model of an individual node.

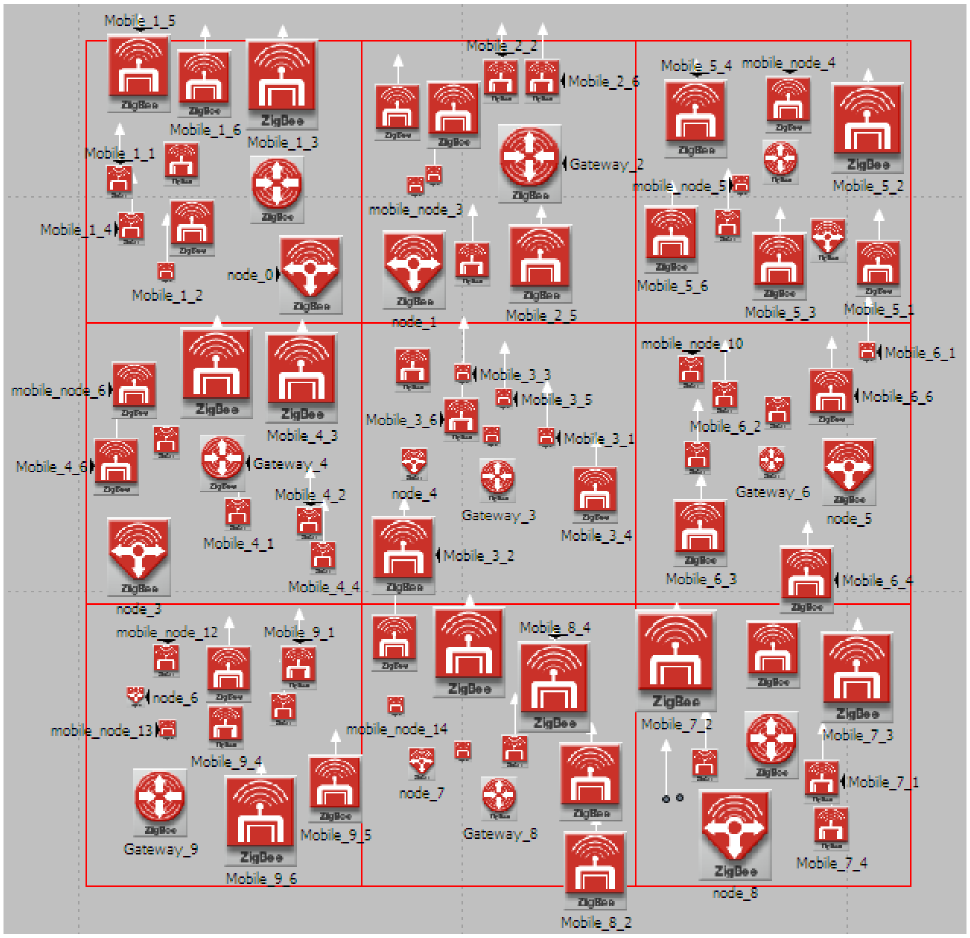

Fig. 8: Network Model

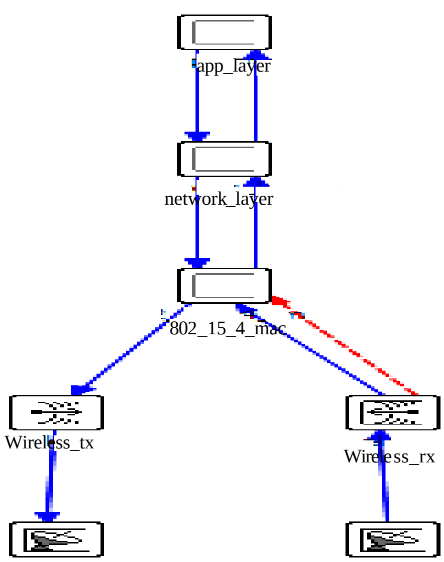

Fig. 9: Node Model

Table 2: Simulation parameters

Parameters	Values
Topology	Tree
Simulation time	30 min
Number of nodes	100
Trajectory	vector
Number of retransmission	2
Max. No. of backoffs	3
Transmission band	2450 MHz
Max. No. of groups	9
Packet size	1024 bits
Data rate	CBR

Parameter: The parameters used in simulation are given in Table 2. Parametric values given in Table 2 are retrieved from MATLAB results (Max. No. of groups). MATLAB has been used to implement the developed algorithm, it supports strong mathematical model of new proposed approach whereas the wireless nature of the network can't be developed in MATLAB. Hence, OPNET environment is utilized to perform simulations with derived values.

RESULTS AND DISCUSSION

This study performed the performance evaluation of MIC-GS with beamforming. Simulation is the conduct of different sources and mobility models.

Throughput: A network of 100 nodes is taken for simulation. The grouping algorithm performs group assigning process in heuristic way such that all the nodes in a group are not hidden to each other. Through technique unnecessary transmissions are reduced. Thereby, packet drop has been removed which increases the overall throughput of the network as shown in Fig. 10 from the result, it is absorbed that in HNAMe the possibility of hidden node collision is more. Therefore, throughput also decreases continuously due to the packet drop. But the newgroup forming in a cluster region has an improved throughput.

Delay: Number of retransmissions in network due to the hidden node collision has been reduced in MIC-GS. Hence, it is observed from Fig. 11 that proposed technique has a constant delay when compared to HNAMe.

Media access delay: In a network without proper grouping, every node contends for time slots in a superframe. Nodes which contend first will get the scheduled time slot. Hence, the remaining nodes run their backoff timer to contend for the next time. Therefore, delay increases when this backoff time increases. MIC-GS maintains a proper node grouping with steady backoff time thereby it obtainsan improved media access delay as shown in Fig. 12.

Queuing delay: It is observed from the Fig. 13 that queuing delay of proposed work varies much from HNAMe. This is due to the proper scheduled transmission and reception of the packets in a node group of MIC-GS.

Load distribution: Figure 14 shows variation of packet flow when number of nodes increases in a network. Node groups are scheduled to transmit in a particular set of timeslots like Guaranteed Time Slots (GTS) in standard ZigBee superframe. Hence, the flow of packets across nodes increases without packet drop in modified grouping strategy.

Control traffic received: Control signals from a node usually broadcasted to coordinator. Hence, the packet

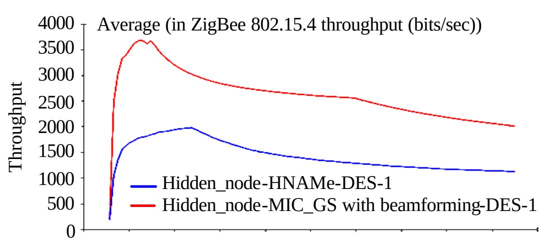

Fig. 10: Throughput

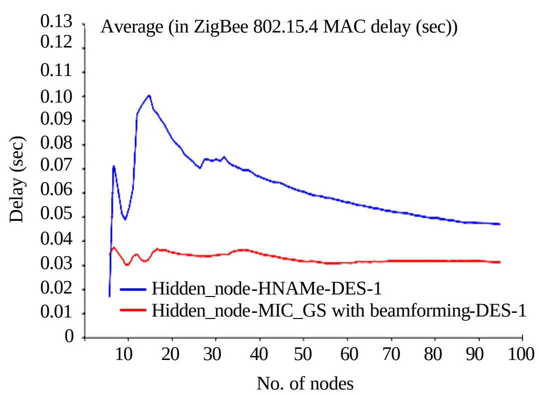

Fig. 11: Delay

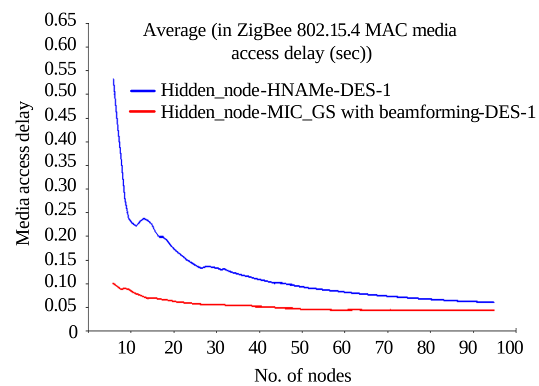

Fig. 12: Media access delay

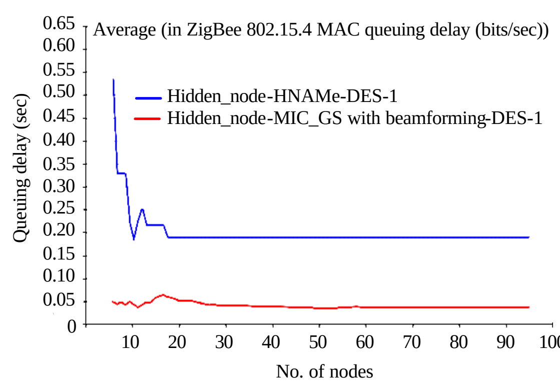

Fig. 13: Queuing delay

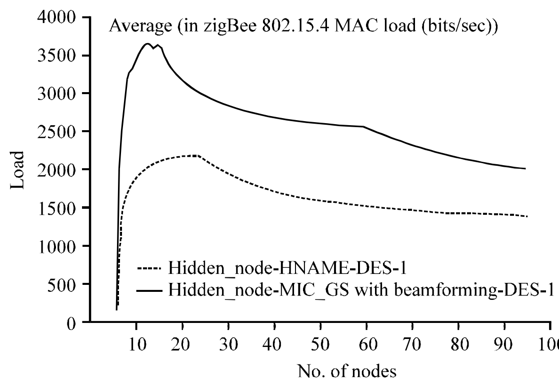

Fig. 14: Load distribution

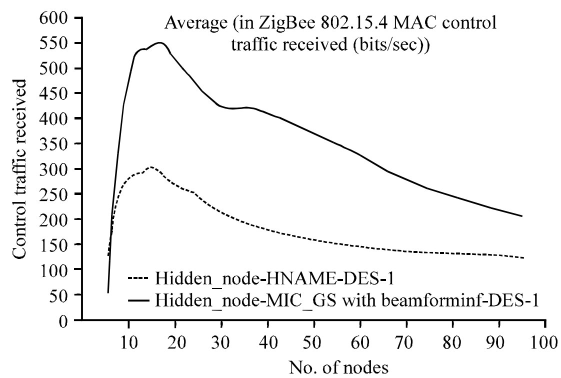

Fig. 15: Received control traffic

drop is more in conventional design. MIC-GS uses beamforming technique to transmit the control signals for signaling process. Beamforming technique reduces the packet drop through transfer of control signals in a directed beam to a selected coordinator. It is observed in Fig. 15.

Power consumption: Total power consumption of a network is analyzed by developing a mathematical modeling in MATLAB simulation environment. Simulation results for 100 nodes are shown in Fig. 16. The power consumption for one node is:

$$P_{node} = P_{tx} \times T_{tx} + P_{rx} \times T_{rx} + P_{idle} \times T_{idle} \qquad (7)$$

where, the power consumption in reception mode (P_{rx}), transmission mode (P_{tx}) and the idle mode (P_{idle}) is 24 mA, 29 mA and 1 μA. Percentage of transmission, reception and idleness are represented as T_{tx}, T_{rx} and T_{idle} of a particular node. The average power consumption of each node is:

$$P_{average} = \frac{\sum_{0}^{N} P_{node}}{N} \qquad (8)$$

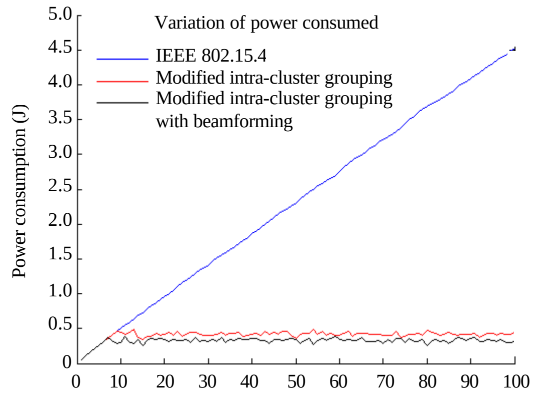

Fig. 16: Power consumption

Power consumption which is measured in percentage of total consumption for total number of nodes in WSN is shown in Fig. 16. It is absorbed that when traffic load increases above 8 nodes, MIC-GS with technique power consumption is much less when compared to IEEE 802.15.4 standard and MIC-GS. Because MIC-GS not only balance probability of transmission in each group but also decreases the wakeful time of time each node which causes energy wastage due to hidden node collision.

CONCLUSION

This study presents implementation of modified intra-cluster grouping scheme in IEEE 802.15.4 ZigBee networks. It is an efficient grouping scheme in sensor environment performed during node grouping to avoid hidden node collision completely. This grouping scheme is a reliable technique which also reduces energy wastage during the new node joining process. It performs group assignment of new nodes without changing nodes which are assigned to some other groups in a network. From the simulation results, it is understood that in a hidden scenario proposed grouping approach shows higher throughput than the standard protocol and also power consumption could be much less than standard protocol while performing grouping in a cluster region. Therefore, by analyzing these results this modified standard ZigBee protocol could be used in sensor environment.

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