Cluster Based Approach to Minimize Delay in Energy Aware Routing for ieee 802.11s Wireless Mesh Networks under Mobility Conditions

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***Abstract*—Minimization of delay in data collection at base station is one of the major concerns in cluster based Wireless Mesh Network. There exists few other techniques for the cluster head selection in wireless mesh network such as selecting a node with maximum energy as a cluster head. In this work, We consider dynamic nodes with single hop topology with in the static cluster. To minimize the delay that occurs in transmission and reception of data, the proposed model includes four modules namely, Cluster head selection, slot allocation, slot scheduling and data collection process. In proposed model, cluster head selection is based on the maximum energy, number of links and link duration. Link duration is considered in order to avoid the link breakage that occurs before the transmission of data. Slot allocation is based on the available energy (E_avail) and the required energy (E_req). Slot scheduling is carried out based on the link duration. A node with minimum link duration will be given higher priority to avoid re-transmission that indirectly results in minimization of delay. Data at the base station will be collected as they are scheduled. Mathematical model of the proposed model is presented in this work and it shows that proposed model minimizes delay compared to the existing there by improving network efficiency.**

I. Introduction

Wireless mesh networks(WMN) are collection of highly distributed autonomous mesh that work cooperatively, monitor the physical, environmental conditions and transmit the data to required destination. Mesh nodes are capable of gathering information through other connected nodes in the wireless mesh network and send to the base station. Wireless mesh networks are battery powered devices and hence energy saving is always a challenging task. In recent days, many algorithms are proposed to overcome energy saving problem. However data collection efficiency is usually compromised in order to gain longer network lifetime. The two main operations of mesh nodes are data dissemination, the propagation of data throughout the network and data gathering, which is aggregation of data from source to base station. Data collection efficiency is affected by delay that can occur during transmission from mesh nodes to base station. Delay is the latency in the arrival of the packet to the destination from its source. It comprises of transmission delay, propagation delay, nodal delay and queuing delay which affects the performance of data collection. Base station is composed of transceiver which is a mesh-less node connected to the host computer and acts as the interface between BS and mesh node. WMN's purpose to to send data to the BS, which implies request moves from base to mesh nodes and sensed data moves in the opposite direction. In the cluster based approach clusters are formed and a node will be selected as cluster head(CH) which plays an important role in data transmission and reception. A number of approaches have been proposed for selection of cluster head [6].

Wireless mesh networks are mainly battery powered devices. These type of network includes nodes which are mobile and has the ability to to withstand to harsh environmental changes or conditions, to handle node failures. One of the major constraint in the WMN is the power consumption by the nodes to transmit or receive data. The energy constraint plays a major role in WMN because it is difficult to recharge the energy for each node in the network. Thus the basic motivation is to reduce the delay that occurs during the transmission of packets between source and destination. Since we consider the link duration of nodes while scheduling, the delay is minimized. The clustering of nodes will reduce energy consumption to some extent. In the existing models, the delay in transmission is the main threat which may result in losing of data. If delay factor is concerned then alteration in energy consumption might occur. A new model must be designed with the consideration of delay minimization and efficient use of energy at nodes which results in boosting of performance of data transmission.

The rest of the paper is organized as follows: Section II define the problem statement and Section III discuss related previous works. Section IV presents the proposed mathematical model for the proposed system and Section V depict the system diagram of the proposed model. Algorithms and their analysis are discussed in Section VI and VII. Section VIII presents the Conclusion and scope for future work.

II. Problem statement

To reduce the delay that occurs during the transmission of packets between source and destination. In the existing models, the delay in transmission is the main threat which may result in loss of data. If delay factor is concerned then changes in energy consumption might occur. A new model must be designed with the consideration of delay minimization and efficient use of energy at nodes which results in boosting of performance of data transmission. further to minimize delay, increase data collection efficiency, increase throughput, decrease network overhead in Wireless mesh network by modifying the existing protocol. The proposed model selects the cluster head based on maximum number of links, available energy, and link duration. The nodes requesting the CH for data collection process is prioritized based on the duration of link between node and CH. Data is collected eventually by the cluster head and sent to the base station.

III. Related works

The authors of [1] have worked on gathering sensed information in a energy efficient manner for a long period of time. Authors present a scheme called PEGASIS (Power Efficient Gathering in mesh information systems) which is a near-optimal chain based protocol that minimizes energy. In the proposed protocol delay is minimized by allowing simultaneous transmissions whenever possible in the network. Work done by the authors of [4] is based on an application domain where wireless mesh networks broadly used is environment data collection and surveillance. Each mesh node periodically collects local measures of interest and transmits them back to the sink node, which is the data processing centre. Each sampling value is associated with the meshs location. The authors of [2] proposed a model which is a two phase clustering scheme in multihop wireless mesh networks. The proposed scheme starts partitioning the network into clusters in phase 1 called cluster formation each with a cluster head. Mesh join the nearest cluster head forming a direct link to it. In phase 2, called cluster restructuring, cluster members are required to search for a neighbour closer than the cluster header within the same cluster to set up a data relay link which offers further improvements in energy conservation and distribution of the cluster heads workload. The authors of [7] discusses about the scheme called Mobile Element Trajectory Control, which will reduce the data collection delay and balance energy consumption in wireless mesh network. The data is collected at all or some of the mesh node and forwarded to the central base station for further processing. The mobile element can act as mechanical carriers collect data from all the nodes and transfers to the base station. It will reduce data collection delay and balance the energy consumption in wireless mesh networks. The authors of [9] have proposed the structure which organizes mesh nodes into clusters of different sizes so that each cluster can communicate with the fusion centre in an interleaved manner. As the distance between nodes in a cluster increases the energy consumption increases. So optimization process is proposed to optimize intra-cluster communication distance. Work done by the authors of [10] reveals the mobile data collectors (MDC) model that are used to provide the connectivity between the sink and partitioning. MDCs collects the data and may provide it either to sink or to neighbouring MDCs so that it would relay it to the sink node. This will increase the data latency. Hence in this model clustering is done so as to reduce data delay with the single sink. Total delay is calculated by considering the rendezvous waiting delay. The author of [5] describes two kinds of queuing delays that can occur in multi-hop wireless networks and they proposed a new delay-efficient TDMA-based distributed scheduling scheme to eliminate the secondary queuing delay. The performance analysis of the scheme, the scheduling overhead is first evaluated in terms of power consumption. Next, the multi-hop packet transmission delay of the proposed scheduling scheme is derived. This scheme works well irrespective of the packet Inter-arrival rate and outperforms the conventional graph colouring. The authors of [8] demonstrate wireless multi hop networks, where data transmission takes from one node to another over multiple links . The main aim of this model is slot assignment and fairness per flow. The authors of [3] describes an Energy-Division Multiple Access Scheme. A new multiple access scheme based on energy discrimination is proposed. This is based on the differences in the average power received by each user. This scheme proposes a new multiple access scheme where several users simultaneously transmit with the same antipodal signalling scheme $p(t)$. The information bit transmitted by each user is recovered by the receiver by using the differences in the average power of the signal received from each user.

From the works carried out till date, we can notice that WMNs are battery powered with limited processing and transmission power. Hence energy consumption is a critical issue. Limited to the structure where all the cluster members are directly connected to cluster head. Only 2 level sink are considered. Scheduling the MDC in collecting data from sink in partition to main sink is considered. Potential delay occurs when data from the closer sources are held back or buffered at an intermediate nodes so as to be aggregated with the dat that are coming from the farther nodes. The potential delay depends on the aggregation function performed on the data. WMN with disjoint partitions detached from the rest of the network due to initial deployment or node failures. The nodes in the WMN are considered stationary and network topology remains constant. Relay nodes have enough memory space to collect all data from cluster(they are mobile). Minimum number of Relay nodes are used and are placed based on relay node replacement. Relay nodes restores connectivity between partitions. Each mesh node has a power control and ability to transmit the sensed data to its neighbouring node or directly to the base station. Mesh network contains homogeneous and energy constrained mesh nodes with initial uniform energy. Every node has location information. Nodes are considered to be static.

IV. Mathematical model for the proposed system

The main goal of proposed model is to cluster the nodes in the network, selecting cluster head, allocating slots for n nodes that requests for data transmission, schedule the allocated nodes and collecting data from these nodes eventually in an optimal way considering efficient energy utilization and minimizing end-to-end delay. Proposed model consists of four algorithms namely Cluster head selection, Slot allocation, Slot scheduling and Data collection.

A. Network model

The model consists of a graph G(N,E) where N rep-resents the number of nodes and E represents the set of links. $n_i(x_i, y_i) \in N$ represents the node i's location in the simulation field. Nodes are distributed randomly within the simulation field. Each node is given a unique node id and cluster id. Packet size of each node may vary and data rate of each link is also chosen randomly.Nodes within the cluster travel with different velocity and pause time along randomly chosen direction. Nodes are clustered based on their location in the simulation area. We consider a single - hop wireless mesh network where base station (BS) remains static and nodes are dynamic within the cluster.Each cluster is bounded by an internal area. If a node reaches the cluster boundary due to its mobility it rebounds with an angle θ or $\pi - \theta$. Communication range of base station and a part of cluster area should overlap with each other. Nodes that are connected directly to the base station are called cluster heads (CH) and are at level 1. All other remaining nodes within the cluster are at level 2 and are connected to their level 1 cluster heads. Every node is not expected to be directly connected to the base station, since it increases congestion and network overhead. Link is established between two nodes n_i and n_j when their transmission ranges R_i and R_j overlap with each other. The equation which determines whether there is a link between two nodes is given based on the distance during which the link is connected, which is given in the Equation 1.

$$d_{ij} = 2r_i cos\beta_{ij} \quad (1)$$

where β_{ij} is the incident angle of $node_i$ in the transmission range of $node_j$ and r_i is the transmission range of node i. Using equation refeq1, it is possible to determine the existence of the link between two nodes and it is given in the Equation 2.

$$l(i,j) = \begin{cases} 1, & \text{if } d_{ij} > 0 \text{ i.e link established.} \\ 0, & \text{no link present.} \end{cases} \quad (2)$$

Fig.1 shows the overlapping of transmission range of one node with the other node's transmission range while transmitting the data.

Due to the mobility node may move out of the transmission range of the cluster head and may result in link breakage and is shown in Fig. 2. Cluster head is required to have maximum energy, maximum link duration and maximum number of

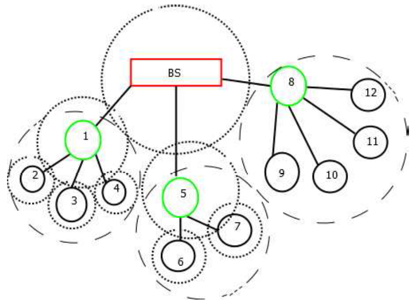

Fig. 1. Overlapping of transmission range

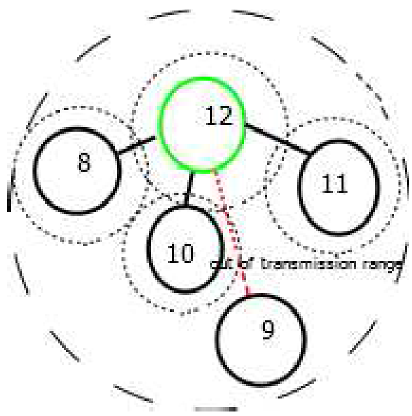

Fig. 2. Link breakage

links with other nodes. Since cluster head is involved in collecting data from other nodes in the cluster, it must have sufficient energy to receive data from requesting nodes and transmit them to base station. Link duration of cluster head should be maximum to avoid link breakage between CH and BS, so that retransmission is reduced considerably. Link duration between the cluster head and base station is given by,

$$ld_{ij} = \frac{d_{ij}}{v_i} \quad (3)$$

where v_i is the velocity of node i, d_{ij} is calculated using Equation 1. Number of links of each node in the cluster is given by,

$$nl_i = \sum_{j=1}^{N_c^i} l_{i,j} \quad (4)$$

where ${N_c}^i$ is the number of nodes in cluster i, $l_{i,j}$ can be determined using Equation 2. Cluster head will be the node with maximum link duration, number of links and available energy as shown in the Equation 5.

$$CH = \max_{i \in N_c^i} (ld_{ij}, nl_i, AE_i) \quad (5)$$

In the process of data collection to serve amd requests, slots are allocated with the help of Time Division Multiple Acces(TDMA) , fixed slot allocation method. Link duration is considered as a parameter to schedule slot. The nodes with minimum link duration will be given high priority. This is done because the nodes with less link duration will go out of the transmission range of cluster head early. Further data collection from the nodes is done using bottom up approach. In the scheduled timeslots the data from respective nodes are collected and transmitted to their cluster head.Data collected will be fused at the cluster head and then transmitted to the base station. Since we consider survivability as a parameter in data collection, this reduces the delay and re-transmission rate. End-to-end connection between source and destination is established at the transport layer. Since the energy calculation is involved during slot allocation, the process is carried out in network layer. Frames are generated and they are scheduled at the data link layer. The bit wise data transmission takes place at the physical layer which represents the actual data transmission. An example of our network model is shown in the Fig. 3. Nodes are clustered into three clusters and data is collected at the base station in the allocated time slot.

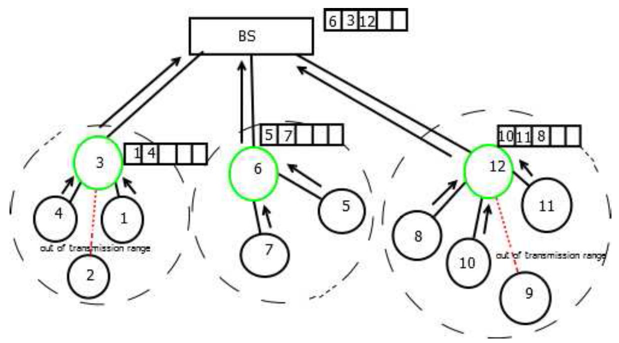

Fig. 3. Network model

B. Objective Function

In the existing system as seen above the delay experienced by the transmission of data from nodes to the base station is high which is not appreciable. Hence we proposed this single hop model where we can minimize the delay without any confinement in network topology. Delay is the time taken by a packet from the source to the destination for which it is being transmitted. When data (packet) is being transmitted from the source to its destined node, data experiences propagation delay, transmission delay, queuing delay, processing delay and delay for link establishment between the nodes. Node can send data only if it is in the transmission range of Cluster head. Here since the nodes are mobile in nature, link duration between the nodes is one of the important parameter to be considered. The nodes having lower link duration is given higher priority and allowed to send its data first. Because the nodes are moving it will go out of the transmission range of cluster head once the link duration is expired. When node with less link duration is given higher priority it can send the data before it goes out of the transmission range of cluster head. Thus reducing delay in link establishment while data collection, which is a mobility factor. We schedule more than one node of different cluster in the same timeslot, this reduces Queuing delay. Thus delay minimization takes place. Since we reduce total number of timeslots for data collection process , the frame size can also be reduced. Delay experienced by the p^{th} packet received at n^{th} node between start and reception of the packet is $D_{n,p}$ can be given by Equation 6

$$D_{n,p} = D_{prop} + D_{trans} + D_{que} + D_{proc} + D_{link\_est} \quad (6)$$

where $D_{n,p}$ is end to end delay, D_{prop} is propagation delay, D_{trans} is transmission delay, D_{que} is queuing delay, D_{poc} is processing delay, $D_{link\ \ est}$ is link establishment delay Propagation delay can be calculated as,

$$D_{prop} = \frac{distance}{propoagation\_speed} \quad (7)$$

where distance is,

$$distance = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (8)$$

for i and j nodes. Transmission delay can be calculated as follows,

$$D_{trans} = \frac{packetsize}{bandwith} \quad (9)$$

Average delay for each packet is given by,

$$Average\_delay = \sum_{n=1}^{N} \sum_{p=1}^{Np^n} D_{n,p} / \sum_{n=1}^{N} Np^N \quad (10)$$

Throughput is the successful data delivery to the destination. Data collected at the cluster head will be fused and then sent to the base station. This reduces the congestion for the base station, thus reducing number of requests being sent to base station. This reduces the data loss (hence no need of data retransmission) and simulation time, increasing the throughput on the whole. $b_{n,p}$ is number of bits being transmitted in pth packet to nth node.

$$Throughput = \sum_{n=1}^{N} \sum_{p=1}^{Np^n} b_{n,p} / T_{sim} \quad (11)$$

Throughput is indirectly proportional to total simulation time hence throughput increases.

C. Proposed model

Cluster Head Selection: The proposed model begins with cluster head selection. For every cluster in the network cluster head is required to transmit the data from other nodes in the cluster to base station. Otherwise many of the nodes in the cluster will try to access the base station simultaneously, increasing collision as well as traffic in the network. Cluster head should transmit the data to the base station, hence it must be in the transmission range of the base station, which can be determined using Equations 1 and 2. The cluster head must be a node which has maximum number of links with other nodes in the cluster. A node with maximum number of links can collect the data from more nodes compared with the node which has less number of links. Hence inorder to minimize the delay, cluster head should have maximum number of links. Base station must select a node as cluster head by considering the factors such as transmission range of base station, number of links, link duration and available energy. Cluster head selection algorithm first finds the nodes which are in the transmission range of the base station and having atleast one link. Link duration of the nodes in the cluster and the base station is calculated using Equation 3 and it is stored as node property. Draining rate of a node is an important parameter to be considered in selecting the cluster head and it is given by,

$$DR_i = \frac{E_I - E_C}{T_1 - T_2} \quad (12)$$

Survivability of nodes can be defined as the time during which the node can survive with its remaining energy calculated using Equation 12,

$$surv_i = \frac{RE_i}{DR_i} \quad (13)$$

decision parameter used by the base station to select the CH is given below,

$$Dp[i] = |ld_i - surv_i| \quad (14)$$

where ld_i is the link duration which can be calculated using Equation 3 and $surv_i$ can be determined using Equation 13. Cluster head will be the node with minimum dp value.

$$CH = min(Dp[i]) \quad (15)$$

Base station maintains a decision table which contains node id,link duration, available energy and survivability as shown in the Table I,

TABLE I. Decision table at BS

Node id	Cluster id	ld	RE	surv	Dp

An optimal node with a little trade off between duration for which link is present $ld(node, BS)$ and the survivability of the link for which the energy present within the node is drained out completely is selected as cluster head. Once the cluster head is selected based on the decision table, base station sends the coordinator message to all the nodes including the cluster head in the cluster. Format of the coordinator message is given in the Table II.

TABLE II: Coordinator message formatt

Node id	Cluster id

Slot Allocation: During the process of slot allocation for n requests from n nodes at the kth time to the CH within the cluster, frames are divided into time slots based on TDMA approach. Before allocating slots for the node the remaining energy in the CH is considered and the energy consumption for receiving and transmitted. The energy for requested packets is calculated and allocation is done based on it. As packet size and number of packets increase ,Energy consumption also increases. With the increase in data rate, the E_c decreases and it can be depicted in Equations below

$$E_c = k \times Np \times PS \quad (16)$$

$$E_c = k/D_r \quad (17)$$

Where Np represents number of packets, PS represents packet size, k is the constant and D_r represent delay data rate Energy is also consumed for sending RRER and RREP packets to establish connection between nodes. Energy consumption of a node for transmitting and reception of packet is given by the following equation,

$$E_c^i = \frac{V \times T \times Ps \times Np \times (I^t + I^r)}{D_r} \quad (18)$$

where V is the voltage, T is the time taken to transmit the packet, I is current, $P\ s$ is packet size, Np is number of packets and D_r data rate of the link. If there is sufficient energy in the cluster head, then slot allocation takes place.

$$AE_{CH}^i > E_c, AE_{CH}^i = AE_{CH}^i - \{E_c + \sum_{l_{i,j} \in E} (RREQ + RREP)\} \quad (19)$$

The nodes having data to be transmitted, sends the RREQ message to the CH. Format of RREQ message is given in the Table III, Number of time slots required for a node to transmit

TABLE III. RREQ Message

Node_ id	Cluster_ id	CH	Np	Ps	D_r

the data is the function of packet size $P\ s$, number of packets Np, and data rate D_r. NT represents the number of time slots required for one node.

$$NT = Ps \times Np/Dr \quad (20)$$

Once the number of time slot is calculated and energy criterion is satisfied slots are allocated. Each slot stores three values namely Node id, Frame number,slot number which is shown in Fig. 4 below. Each node in the cluster has 5 frames and each frame has 8 timeslots.

Once the remaining energy of CH drains and reaches threshold level or the requests are given slots for the process of data collection,the time for completion of the process is calculated. This is done , so that the next cluster head must be selected after that particular time and hence CH selection initiation packet is sent to the BS. If the link duration is less than that of calculated time, the link duration information is sent to the BS as CH will not have access to the BS after this period. Format of initiation packet is as follows.

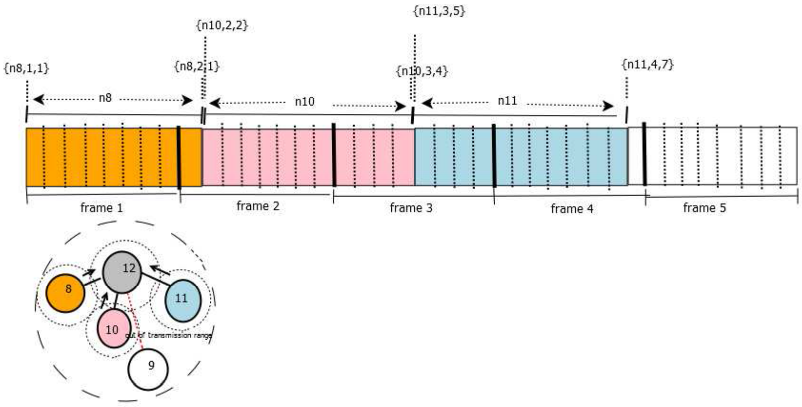

Fig. 4. Slot allocation

D. Slot Scheduling

Each node in the cluster is scheduled/ assigned to a particular time slot, in-order to avoid collision and delay. In this algorithm the link duration is compared between the nodes that are requesting for the data transmission, which are connected to the cluster head (CH). If the node has minimum link duration with the cluster head then highest priority is assigned to the specific node and the node which has maximum link duration with the CH will be given low priority, thereby reducing the link breakage before the transmission of data. Thus the proposed algorithm helps in minimizing the delay and re-transmission rate. Each node requesting for data transmission at the same time are prioritized based on the link duration. The link(i,BS) having highest duration are given low priority. Relative speed between two nodes i and j is given by,

$$v_{i,CH} = \sqrt{v_i^2 + v_{CH}^2 - 2 \times v_i \times v_{CH} \times cos\left(\theta_i - \theta_{CH}\right)} \quad (21)$$

where v_i is velocity of node i and θ_i is angle at which node i moves. Distance during which link is connected, is given by Equation 1 and link duration between a node and cluster head can be determined by Equation 3. The priorities are assigned using Equation 3 as follows,

$$priority\{min\left(ld_{k,CH}, ld_{j,CH}\right)\}\forall k, j \in N \quad (22)$$

Where, $priority\{min\left(ld_{k,CH}, ld_{j,CH}\right)\}$

$$= \begin{cases} Pr\left(k\right) + 1, & \text{if } ld_{k,CH} < ld_{j,CH}. \\ Pr\left(j\right) + 1, & \text{Otherwise.} \end{cases} \quad (23)$$

Fig. 5 shows slot scheduling of Fig. 4. The link duration of node n_{11} is less when compared with other nodes n_{10} and n_8. Hence it is scheduled first. The link duration of node n_{10} is less when compared with other nodes n_8. Hence it is scheduled second.

E. Data Collection

Data collection Algorithm is the main algorithm of this model. With array nodes of the i th cluster and array of cluster as the input, data is collected at the base station. This algorithm is for minimizing the delay in data collection from the nodes to the base station. We know that a node can send data only if it is in the transmission range of receiving node. Nodes in the range of base station is checked and then cluster head selection is one based on maximum energy, link duration with the base station and number of links to the remaining nodes in the cluster. While packets are to be transmitted, nodes make request to the cluster head. Slot allocation is done based on remaining energy. Then slot scheduling is done by considering link duration as the parameter. The nodes having less link duration will be given high priority. According to the schedule done data from the nodes are collected at the cluster head and then stored in a buffer . The data stored in the buffer are fused and then sent to the base station. The fusion of data at the base station helps to reduce the energy consumption. Since we consider the link duration while scheduling, helps to minimize the delay. The Data collection at the base station is shown in the Fig. 6.

V. Conclusion

In this work, we have considered a delay minimization technique for wireless mesh networks with consecutive data collection processes. This is achieved due to clustering of nodes which is done based on the location of nodes. Nodes are connected to the CH in a non-cyclic manner. Base station is static and nodes are considered to be dynamic in nature. The node within the cluster having maximum number of links, high link duration and maximum available energy is selected as cluster head. Slot is allocated based on the remaining energy of node. Scheduling of nodes takes place based on the link duration. The proposed technique shows that more data can be collected in less time with minimum delay, without loss of data thereby increases the performance. Implementation of proposed model with dynamic clustering in the field of wireless mesh network will be our future work.

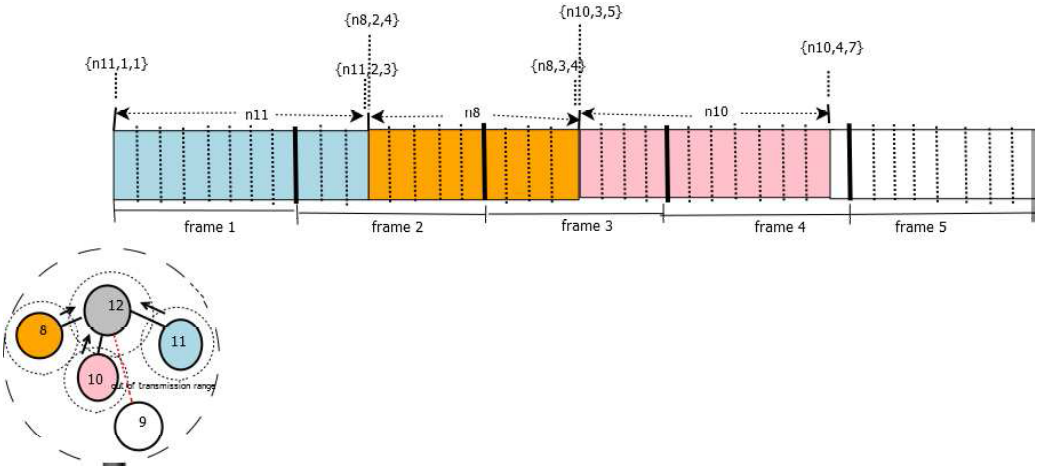

Fig. 5. Slot scheduling

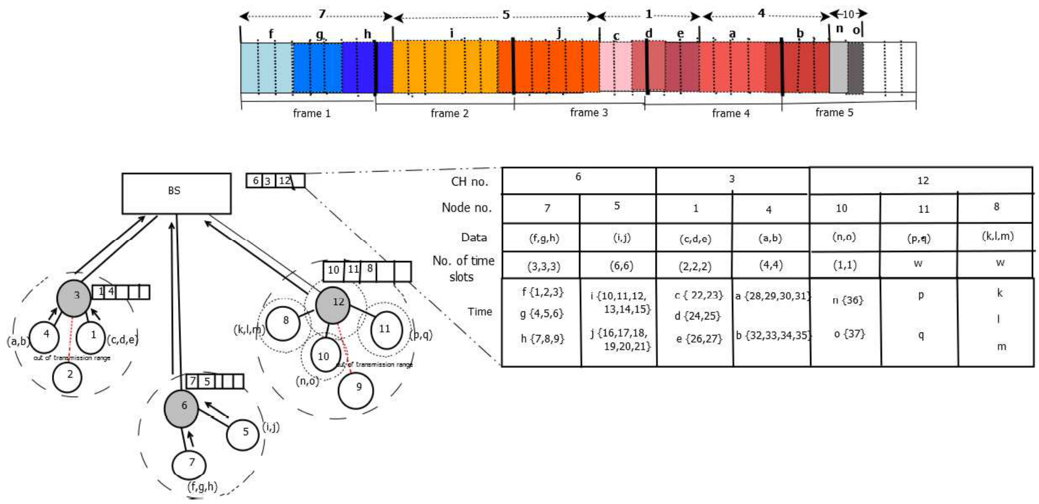

Fig. 6. Proposed model's data collection at the BS

VI. Acknowledgement

Part of this paper has been prepared as a contribution to the state project of the Board of the Ministry of Education of the Russian Federation (task 2.136.2014/K).

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