Chapter 4

Power Consumption and Congestion Control Speed for WBSN

4.1 Introduction

Mobile sensor node deployment and power management are important issues in any WSN system. The WSN is a dense network of sensors which sense the environmental conditions, process and propagate the data towards sink node. Limited battery life of sensor node and unbalanced utilization of energy can affect the lifetime of the entire sensor network. Mobile nodes are used to transmit the data to nearby area where power consumption of the nodes is more. The mobile node reduces the workload and congestion of the nodes which is controlled by balancing the RR according to the buffer occupancy level. In this contribution, we have correlated the existing AODV routing protocol with our new approach to the delivery of power consumption. The performance of the lifetime and energy consumption of the WSN with and without mobile nodes where evaluated various scenarios like changing the number of mobile nodes, location and the speed of mobile node(s). The RR is also balanced to control the buffer occupancy of each node and to mitigate the congestion that occurs in the sensor network.

The simulation shows the increase in the lifetime of the nodes whose power consumption speed is high and thus enhances the life of the entire network. Using the congestion control scheme, the packet delivery ratio increased by 44.80%, packet loss ratio decreased by 83.19% and the throughput increased by 44.80%. The energy consumption rate decreased by 53.4% so the lifetime of a node increased by 5.52%. The packet delivery ratio increased by 29.27%, packet loss ratio decreased by 89.02% and the throughput increased by 29.15%.
4.2 Background

Nowadays, improvements in integrated circuit innovation have made possible the development of a large number of modest and low-power sensor hubs with wireless communication, signal preparing, and remote sensing abilities [118, 119]. A WSN is a highly distributed system of small, lightweight wireless nodes, deployed in large number to monitor the environment or system by the estimation of physical parameter [120]. The sensor network can be described as a collection of tiny sensor nodes which can provide access to information anytime, anywhere by gathering, preparing, and investigating of data [121]. These devices or nodes called sensors which consist of sensing, local data processing, and communicating components like controller, transceiver, also onboard storage and power source i.e. battery. The typical sensor network arrangement is shown in Figure 4.1.

![Figure 4.1: Typical sensor network arrangement](image)

Generally, a WSN consists of seismic sensor used for measuring motion of the ground, infrared sensor for detecting characteristic and movements of surrounding...
The WSN of these special sensor are efficiently used in applications such as forest fire control, thermal sensor for measuring temperature of surrounding environment, humidity in air, vehicle surveillance, noise levels, military, healthcare environment, chemical processing scenarios, etc. Each sensor node is made up of transceivers, microcontroller, external memory, and power sources and defined as:

**Controller:** The controller controls the functionality of other components in the sensor node. It performs various tasks and processes data. The most common controllers are a microcontroller, a general purpose desktop microprocessor, digital signal processors, FPGAs and ASICs etc. can be used as controller.

**Transceiver:** The transceiver works as both transmitter and receiver. The operational states are transmit, receive, idle, and sleep. The transceivers in its receiving mode consume almost same energy as that of idle mode. Whenever the node is not transmitting or receiving the data, it is better to shut it down than to keep it idle.

**External memory:** In sensor nodes, the important factor is the memory. The on-chip memory of a microcontroller is mostly used. Flash memories are used due to their low cost and high storage capacity. Two categories of memory based on the purpose of storage are: user memory used which is used for storing personal application related data and program memory used for programming the device.

**Power source:** The important component in any electronic or mechanical device is the power or the battery. The sensor node consumes power for sensing, communicating, and data processing. Two power saving policies are being used. These are the Dynamic Voltage Scaling (DVS) and the Dynamic Power Management (DPM) policy. The DVS scheme is based on varying the power level due to workload. DPM helps to conserve power by shutting down those part of the sensor node that are idle.

In WSN, the limited battery life of sensor node and unbalanced consumption of energy can affect the coverage of the network, connectivity, reliability, as well as lifetime of the whole sensor network. In the WSN, there are many different issues like flow and congestion control, loss recovery, quality of service, fairness, reliability, energy efficiency, etc. To address these different issues, a lot of work has been done. Among them, energy saving is a most critical issue because of the battery life as the sensors and the applications are used. It is almost impossible to change the battery of the sensors. To control or avoid the congestion as well as to save the bandwidth and energy of the nodes, the data sending rate of the nodes close to the source should be controlled. To balancing the sending rate of each flow as early as possible and save the scarce resource at the nodes close to the sink node, all intermediate sensor nodes are categorized into near-source nodes and near sink node. The probability of the congestion is high to the nodes those are
near to sink due to convergent nature of the WSN. Based on this simulation results, this proposed work that will increase the life of the entire network by balancing energy consumption, speed, and reducing the congestion.

### 4.3 Related Work

The major issue in the WSN related to flow and congestion control is studied in detail [79, 138, 139, 140, 141, 142, 143]. The loss recovery are discussed in [144, 145], whereas the quality of service issues are focused in [146, 147]. The fairness factor in WSN is addressed in [78] and reliability matters are investigated in [148, 149]. The energy efficiency [150] being the most critical issue in WSN due to limited battery power is discussed in [118, 151, 82].

The congestion control saves the bandwidth as well as the energy of the nodes. In order to speed-up the transmission of packets, two types of node namely near-source node and adjacent sink node are introduced in the network. The probability of the congestion is high to the nodes those are near to sink due to convergent nature of the WSN. In [78], the authors proposed the FACC scheme in which the queue at each node is maintained with two thresholds $Q_l$ and $Q_h$. If the queue occupancy is less than $Q_l$, the packet is accepted. On the other hand, if the queue occupancy exceeds $Q_h$, the arriving packets will be dropped, which indicates that the traffic is overwhelming and rate of all passing flows should be reduced. A WM consisting of a flow ID along with node ID is generated by the sink node once the congestion occurs.

Like FACC, ECODA [79] also maintains a queue dual buffer thresholds and weighted buffer difference for congestion detection. When congestion occurs, packets are dropped to alleviate congestion. The total number of packets are $N$, two thresholds $Q_{\text{min}}$ and $Q_{\text{max}}$ are used. If $0 \leq N \leq Q_{\text{min}}$, all incoming packets are buffered because queue utilization is low. If $Q_{\text{min}} \leq N \leq Q_{\text{max}}$, some packets with low dynamic priority are dropped or overwritten by subsequent packets with high dynamic priority and the expected average buffer length increases. If $Q_{\text{max}} \leq N \leq Q$, some packets with high dynamic priority are dropped or overwritten, then the expected average buffer length increases. Once the source node receivers a backpressure message it immediately adjusts its transmission rates in line with receiver or multihop receivers if exit.

The route from source to destination i.e AODV protocol is discovered only when the source has data to send [80]. If no information is available, it broadcasts route request (RREQ) packet to find the path to the destination. When any node receives the RREQ packet, it also checks in its own routing table. If the route is available, then the node replies back by sending route reply packet (RREP) with the path to
reach the destination. The main drawback of AODV protocol is multiple packets are needed to be transferred. In response to a single request packet, multiple reply packets are generated. The path loss occurs in the modes which imbalance the network power consumption. The high energy consumption rate is controlled by comparing energy consumption speed with different nodes.

The use of mobile node i.e. either sink or sensor node helps to reduce the number of transmissions. Authors [81] proposed a new technique for data distribution using mobile sink groups C-SGM. The total sensing field $F$ is divided into the coarse-grained grid. If two different nodes send a notice at the same time, the node with the lowest identifier wins and becomes the header. When the energy of the header node goes below the certain threshold, it reports the header node reselection inside its cluster.

In [82], the authors proposed a new strategy in which all intermediate nodes in between sink and source node cooperate in the packet forwarding. When any node in the intended path fails to receive the data packet and send the acknowledgment to the sender i.e. failing node and the sender node will work as a cooperative node. This cooperative node forwards the data packet to the next hop node and sends the acknowledgment to the sender of the packet. Each node multicast the packet to all other nodes that are within the communication range of that node. The other nodes sense the channel which is silent, the cooperative node sends the acknowledgment to the sender and forward the packet to next hop node. It is possible that there can be many nodes which act as a cooperative node or not even a single one. A timer is set with each node to decide which node will reply back and act as a co-operative node if there are many nodes. This timer is called as backoff timer. Then the node having shortest backoff timer will reply back. Other nodes which are currently sensing the channel turn off their timer by overhearing the acknowledgment. The comparison with existing solution as shown in Table 4.1.

### 4.4 Sensor Networks

Some of the features of sensor networks include the following:

1. Sensor nodes are prone to failures.
2. Mobility of nodes.
3. The topology of a sensor network changes very frequently.
4. Sensor nodes are densely deployed.
5. Ability to withstand harsh environmental conditions.
<table>
<thead>
<tr>
<th>Proposed Idea</th>
<th>Approach</th>
<th>Strength</th>
<th>Weakness</th>
</tr>
</thead>
<tbody>
<tr>
<td>FACC [27]</td>
<td>Queue maintained with two thresholds $Q_l$ and $Q_h$.</td>
<td>1) Compared to no congestion scheme and backpressure, provides higher throughput, less packet loss, less power consumption; 2) improve channel utilization, reduces the interference; 3) The starving problem for the long flows is resolved, it achieves better fairness.</td>
<td>1) Backpressure message increases traffic in the network.</td>
</tr>
<tr>
<td>ECODA [21]</td>
<td>Maintains a queue dual buffer thresholds and weighted buffer difference for congestion detection.</td>
<td>1) Provides higher throughput with reducing packet loss than the CODA; 2) CODA, there in no too many ACKs, the energy consumption is less; 3) Compared to CODA, the end to end delay is less; 4) It uses the priority of the data packets and provides weighted fairness.</td>
<td>1) Buffer is in reject state, drop the higher priority packets or may be delayed by newly arrived packets.</td>
</tr>
<tr>
<td>AODV [32]</td>
<td>Broadcasts route request (RREQ) packet to find the path to the destination.</td>
<td>1) Increase the average lifetime of the nodes by putting then off; 2) Balance the energy consumption of the network.</td>
<td>1) Node is turned off due to high energy consumption speed, then again to find the new route. a) Increase number of packets to transfer; b) Increase delay; c) Stop the data transfer of other nodes; d) Cause congestion. 2) If no route available, data is buffered. If buffer goes full, Cause packet loss.</td>
</tr>
<tr>
<td>C-SGM [33]</td>
<td>New technique for data distribution using mobilesink groups C-SGM.</td>
<td>1) All the sensors consume equal battery power as the role of the header is changed continuously i.e. balanced energy consumption is achieved; 2) Data is distributed via almost the shortest path.</td>
<td>1)As the data is forwarded by towards the header node,it is possible to increase the number of hops; 2) Number of messages are required to send for header advertisement each time when header change and location update loss.</td>
</tr>
<tr>
<td>EECC [31]</td>
<td>All intermediate nodes in between sink and source node cooperate in the packet forwarding.</td>
<td>1) This EECC protocol reduces the number of retransmissions as the cooperative nodes help in the packet retransmission; 2) The energy consumption is also reduced by reducing the retransmission; 3) The network performance is improved; 4) The overall delay is minimized.</td>
<td>1) If cooperative nodes are available, else it is pure retransmission; 2) All cooperative nodes have to receive and store the data from all sensors till acknowledgment does not reach the destination.</td>
</tr>
<tr>
<td>Proposed AODV</td>
<td>This proposed work increases the lifetime of the nodes whose power consumption speed is high and enhances the life of the entire network.</td>
<td>1) Detect and reduce the congestion. 2) Control the node wise traffic flow. 3) Reduce packet loss ratio (PLR). 4) Increase the network lifetime. 5) Increase packet delivery ratio(PDR) 6) Increase throughput. 7) Balance the energy consumption of all nodes in the network. 8) Reduce energy consumption.</td>
<td>1) This protocol is suitable only for event-driven WSN. 2) The protocol needs extra nodes i.e. mobile nodes. 3) Extra overhead of maintain the mobile nodes. 4) Need to check that the intermediate node or source node is really a part of our network (that is security challenge).</td>
</tr>
</tbody>
</table>

7. Sensor nodes are limited in power, computational capacities, and memory.

8. Sensor nodes may not have global identification because of the large amount of overhead and the large number of sensors.

4.4.1 Protocol Stack of Sensor Networks

The sensor networks follow the general rules of networks concerning their protocol with the following layers: Application, Transport, Network, Data-Link and Physical [152]. Though, due to specific characteristics of these networks especially power constraints or specific application tasks, some of these layers could merge in one. Moreover, some of the functionalities of each layer, can be very different than classical Transmission Control Protocol/Internet Protocol (TCP/IP) protocol stack. The major functions of the physical layer include a selection of transmission frequency, generation of a carrier frequency, detection of a signal in the environment, modulation of data and its encryption. All these functions are carried out in such a way that the total energy consumption is minimized. Data link layer deals with the multiplexing of data streams, data frame detection, medium access and error control. Due to power constraints, WSNs implement specific MAC protocols with the power conservation and data-centric routing. The design of MAC protocols embodies the achievement of at least two targets. The first objective is the creation of a specific network infrastructure that can self-organize and, to be able to establish connections among thousands of nodes. The second target is the fair resource allocation between all nodes. Existing MAC protocols fail to meet these objectives because the power conservation is a secondary concern in their development. These MAC protocols are not designed to provide self organization of the network during the initial deployment or in a case of nodes failure, due to power limitations. Two efforts for MAC protocols that meet these requirements are the Sensor-MAC (SMAC) and CSMA MAC [153]. Network layer design is based on the power considerations of the system. WSNs embody attributed based addressing and location awareness. The simplest and mostly spread network protocol is flooding. Each node broadcast its data to all other nodes in the network until these data reach the destination. The message in terms of packets from network layered is segmented into manageable blocks in the transport layer at source subnet while the same block is reassembled into packets at destination subnet. Transport layer makes use of TCP and User Datagram Protocol (UDP) as flexible protocols. TCP here is flexible in terms of adjusting the data transmission rate at sender side and the same is not possible in UDP. Application layer protocol is paramount importance as it addresses the implementation issues of some major functions such as
data management, data fusion, positioning, and clock synchronization.

4.4.2 Congestion and Energy Consumption

The congestion control is one of the major issues in WSN. Some of the nodes transmit data at a higher rate than receivers capacity. Thus the buffers at the receiver may overflow which results in congestion. All of the sensors get active when an event is detected and all sensors start sensing, processing, and forwarding the data to the sink node. The many to one nature that is the convergent character of the WSN results in the congestion to the nodes those are near to sink node. Limited bandwidth, high data sending rate are also significant factors in the congestion. Congestion results in buffer overflow, a loss of packets, comprehensive queuing management [154], and reduction in overall system throughput. The power with the sensors is very limited and the lifetime of the network depends on the battery. If the energy of the sensors within a particular area of the network drains, the network connectivity may be lost. Congestion causes packet loss which results in retransmission it ultimately leads to the energy consumption. The transport layer plays a vital role in controlling the congestion by adjusting an appropriate transmission rate within limit from sender to receiver. For this congestion control it is essential to detect where congestion has occurred. Accordingly the sender and receiver are notified, the transmission rate is then adjusted according to receivers capacity and sender is notified to transmit within this limit. The event driven nature of the WSN is the greatest challenge in the congestion control mechanism.

4.4.3 Effect of Energy Consumption on Sensor Network

The energy consumption of a single node affects the entire network. It directly affects the network lifetime, performance of the network, reliability, connectivity, and coverage of the network. The total energy of the sensor is utilized to sense the signals in the environment and process the data for transmitting to the sink node. Some of the energy is also used to forward few of the packets to other nodes in the network. The sensor may run out of energy after a lot of workloads, and thus it gets disconnected from the network. Due to this disconnected node, the workload on the other nodes increases from the nearest sink node. The node with high data traffic utilized more energy consumption rate and are declared as critical nodes. These critical nodes may limit the overall lifetime of the network [118]. To improve the network lifetime, energy of all nodes should be consumed equally. In a case of the fixed nodes, connectivity between two nodes is stable, where as it is changing in moving sensors. Energy depletion of a single node can also cause to break the connectivity of the network. The unnecessary energy
consumption can be avoided by reducing the amount of data to be transmitted i.e. RR, reducing the number of reporting sensors, shortening communication range, proper clustering [151] or mobility [81, 155]. Proper deployment of sensors [156] or good transmission [118] and routing policies [157] also help to increase the network lifetime. However, reductions of energy consumption of single node as well as entire network has to be controlled.

4.4.4 Clustering

All the node are organized in a clustered structure each having a cluster head. Each node in the cluster transmits its data to sink node. The redundancy in the data collected from the nodes is decreased and then exchanged with the base station by the cluster head. The reduced redundancy results in less overhead and faster communication useful to achieve balanced energy consumption. In [158], authors proposed energy efficient, fair clustering scheme. In [151], authors proposed an energy efficient clustering scheme. Some sink nodes in the network can result in the faster communication.

4.5 System Design and Methodology

It is assumed that the sensor in the network is topologically arranged in a random manner. Each sensor has some spatial limit to measure a rate of passing the data to the sink nodes. This spatial limit is predefined in such a way that the transmission energy is minimized, which in turn extends the overall lifetime of the sensor.

4.5.1 Single Hop Mode

At the point when the sensor nodes use single hop communication, there is no transferring of packets. Every node straightforwardly transmits its packet to the cluster head. Since the communication is direct between the sensor nodes and the cluster head, one and only node should forward at once, and a dispute less MAC is favored and accepted. The sensor node at the farthest distance from its cluster head (at a distance $a$) in a single hop network consumes the highest energy than other nodes. The battery parameter and energy requirement are confirmed in line with the worst case energy consumption of the sensor nodes. Hence to ensure a lifetime of at least $T$ cycles, we require that the battery energy of the sensor nodes in the single hop communication system $E_s$ be

$$E_s = T(l + \mu a^k)$$ (4.1)
Nodes may utilize power control to save energy and to reduce interference with the neighboring clusters. However, this has no effect on the problem of battery dimensioning which needs to represent the most pessimistic scenario in energy expenditure. Since the area of the region is $\pi A^2$, we can approximate each cluster to be a circular region of area $\frac{\pi A^2}{n_1}$, i.e., of radius $\frac{A}{\sqrt{n_1}}$. When single hopping is utilized within the cluster, using (4.1), the required battery energy of a type 0 node $E_0^s$ is [159]

$$E_0^s = T(l + \mu(\frac{A}{\sqrt{n_1}})^k) = T(l + \frac{\mu A^k}{n_1^{k/2}})$$  \hspace{1cm} (4.2)

### 4.5.2 Network Connectivity

We consider a WSN where different sensors are arbitrarily and reliably passed on over the system zone. Two critical measurements for WSNs are connectivity and coverage. For the nodes to effectively utilize multihop communication, it is important to guarantee that any event the condition for node connectivity is met. For $n$ sensor nodes randomly conveyed over a unit area, each having transmission range
If CN = 1
Start
Call receive packet ( )
Process input packet and 
check the CN bit
Continue the packet forwarding ... 
congestion occur and 
notification received
Adjust the reporting rate Forward the packets with 
normal rate
No
Yes

Figure 4.3: Flowchart for AFRC Algorithm

$r(n)$, the probability of node connectivity is given by [118]

$$pr(Connectivity) \geq 1 - ne^{-\pi nr^2(n)}$$ (4.3)

Normalizing the above relation for ‘n’ sensor nodes conveyed over the division having area $\frac{1}{2} \theta R^2$ rather than unit area and the desired probability for network connectivity being at least $p_{con}$, the base transmission range required by every sensor, signified as $r_{con} (=r(n))$, is given by

$$r_{con} \geq R\left[\frac{\theta}{2n\pi} \log \frac{2n\pi}{\theta(1 - p_{con})}\right]^{\frac{1}{2}}$$ (4.4)

4.5.3 Congestion Detection

Let’s consider a set of ‘N’ sensor nodes, where $N = \{N_1, N_2, \ldots, N_i\}$
Let the flow originating from node $N_i$ be $f_i$ and let $r_i$ be the rate at which flow $f_i$ is admitted into the network [138].
Adaptively assign flow $f_i$, rate $r_i$ based on queuing theory (M/M/1 Model).

$$BS_{unoccupancy}^i = BS_{max}^i - BS_{occupancy}^i$$ (4.5)

where, $BS_{occupancy}^i$ = Current queue length of node $N_i$  
$BS_{max}^i$ = Maximal buffer size of node $N_i$

Node $N_i$ detects the queue length and accordingly sets the values of congestion notification(CN) bit.

$$CN = \begin{cases} 
0, & \text{if } BO(t - 1) < BO(t) \\
1, & \text{if } BO(t - 1) > BO(t) 
\end{cases}$$ (4.6)

where, BO (t - 1) is buffer occupancy of previous node and BO (t) buffer occupancy of current node.
Figure 4.5: Flowchart for Proposed Protocol

Let Buffer Occupancy (BO) at node $N_i$ is currentpr.
If currentpr $\geq 80$ then set $CN = 1$ and decrease RRs.
Else increase RRs.

Equation (4.7) is obtained from theoretical results of queuing theory for finding the different values of buffer occupancy by varying RRs. Then theoretical results are compared with results of a simulation.

From results, the confidence value is calculated which is good in case of a logarithmic equation. Hence, this equation is considered in Adaptive Flow Rate Control (AFRC). For Differed Reporting Rate (DRR) algorithm,

$r_i(t + F) = r_i(t) + A$, If $CN = 0$

$r_i(t + F) = r_i(t) - A$, If $CN = 1$

$$CN = \begin{cases} 0, & \text{if } BO < \alpha \\ 1, & \text{if } \alpha < BO < \beta \\ 1, & \text{if } BO \geq \beta \end{cases} \tag{4.7}$$
Where, $F$ is the frequency of rate update and depends on the network status. ‘$A$’ is the amount of additive increase or decrease. Total rate, $r_i(t)$, is based on the CN of nodes.

### 4.5.4 Power Dispersion Technique

Assume that ‘$InitEng$’ represent the initial energy of the node, ‘$RemEng$’ indicates remaining energy, and time indicates the period that node takes to consume energy. The energy consumption speed ‘$ConsSpeed$’ of each node is computed using the equation (4.8) as below.

\[
ConsSpeed = \frac{InitEng - RemEng}{Time}
\]  

(4.8)

The total period during which the node keeps on receiving and transmitting packets without fail is known as it lifetime. Which is calculated using the formula given in equation (4.9) as below.

\[
Lifetime = \frac{InitEng}{ConsSpeed}
\]  

(4.9)

To find remaining energy ‘$RemEng$’ of the node can be calculated by following formula.

\[
RemEng = InitEng - ((PktT.TEng) + (PktR.REng))
\]  

(4.10)

where, $PktT$ = Number of packets transmitted by the node, $PktR$ = Number of packets received by the node, $TEng$ = The amount of energy required to transmit a packet, $REng$ = The amount of energy needed to receive the packet.

\[
RemainTime = \frac{RemEng}{ConsSpeed}
\]  

(4.11)

The above formula is to calculate the remaining lifetime left to the node. Total consumed energy can be calculated as

\[
TotalConsumedEnergy = InitEng - RemEng
\]  

(4.12)

and average energy per hop is

\[
AverageEnergyPerHop = \frac{TotalConsumedEnergy}{N_h}
\]  

(4.13)

where, $N_h$ = Number of nodes per hop
Table 4.2: Mathematical Notations

<table>
<thead>
<tr>
<th>No</th>
<th>symbol</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$I_p$</td>
<td>Incoming flow of packet</td>
</tr>
<tr>
<td>2</td>
<td>$C_{pr}$</td>
<td>Current packet ratio</td>
</tr>
<tr>
<td>3</td>
<td>$C_p$</td>
<td>Choke packet</td>
</tr>
<tr>
<td>4</td>
<td>$D_c$</td>
<td>Detected congestion</td>
</tr>
<tr>
<td>5</td>
<td>$W_b$</td>
<td>Watch buffer occupancy consistently</td>
</tr>
<tr>
<td>6</td>
<td>$C_b$</td>
<td>Current buffer occupancy</td>
</tr>
<tr>
<td>7</td>
<td>$P_n$</td>
<td>Previous node</td>
</tr>
<tr>
<td>8</td>
<td>$F_r$</td>
<td>Flow rate</td>
</tr>
<tr>
<td>9</td>
<td>$N_h$</td>
<td>Number of hops</td>
</tr>
<tr>
<td>10</td>
<td>$N$</td>
<td>Sensor node</td>
</tr>
<tr>
<td>11</td>
<td>$R_{ca}$</td>
<td>Rate control adjustment</td>
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<tr>
<td>12</td>
<td>$N_{fr}$</td>
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<tr>
<td>13</td>
<td>$C_{ql}$</td>
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</tr>
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<td>14</td>
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</tr>
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<td>17</td>
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<td>Energy consumption speed</td>
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<tr>
<td>19</td>
<td>$T$</td>
<td>Threshold</td>
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<tr>
<td>20</td>
<td>$m_n$</td>
<td>Mobile node</td>
</tr>
<tr>
<td>21</td>
<td>$d_n$</td>
<td>Drought node</td>
</tr>
</tbody>
</table>

4.6 Description of Proposed Algorithm

Our previous work on congestion control and minimization of power congestion speed [160] is further extended in this chapter.

In this (Algorithm 4), to detect congestion in the sensor network, buffer occupancy method is used. If buffer occupancy at sensor node is greater than the specified higher threshold value, then CN bit is set, and explicit notification is sent to previous nodes. After receiving this packet, all sensor nodes have to decrease the flow rate. If buffer occupancy crosses the lower threshold value, then CN bit is reset and sensor nodes can increase the flow rate.

In DRR (Algorithm 5), the sensor node which is near to sink has minimum RR, and it will go on increasing as we go away from the sink. For this, first, the distance
Algorithm 4: Congestion Detection Algorithm:

Input: $I_p$, $C_pr$, $C_p$
Output: $D_c$
1. Require: Watch buffer occupancy consistently;
2. $W_b$
3. if $I_p = C_pr$, then $C_pr = C_b$;
4. if $C_pr > 80$, then set CN bit;
5. Send $C_p$ to $P_n$ with $\alpha$;
6. $P_n < F_r$;
7. When $C_pr i = 60$;
8. Reset CN bit;
9. $P_n > F_r = D_c$;
10 Repeat step 3 - 9;
11. Apply DRR;

Algorithm 5: DRR Algorithm:

1. Require: Hop-count in the path from source to sink;
2. Compute $N_h$;
3. Estimate RR;
4. foreach $N$;
5. Set $N$ near to sink RR;
6. Each $N = R_{ui}$;
7. Repeat step 1 - 4;

of every sensor node from the sink is calculated. Then, the RRs for every sensor node are estimated. To estimation of RR for each sensor node, AFRC (Algorithm 6) is used.

Congestion control by using AFRC algorithm mainly run on each node including source and sink of the network with minimal functionality at the source nodes. The major events such as detection of a signal, transmission, reception of data packets, processing the data, etc. are generated by the source node in line with the frequency band provided to it. Thus the data packets are received, processed and forward to the next node via hops if the link to the destination is free. Congestion may occur due to speed mismatch of the sender with a destination node. As a result of congestion, data packets are lost, and more energy is consumed with no produc-
tive work. To avoid this, proposed algorithm runs continuously on the node, and whenever the buffer occupancy crosses a certain threshold value, algorithm sends the message to its previous node i.e. alert message of congestion is going to occur in the network. And as per the flow rate control, the bit is set in the packet; it will decrease the flow rate till the buffer occupancy reaches to the desired level. The mobile node is nothing but an extra node in the network which is put near the sink node. This mobile node moves to the node where the power consumption speed is more. The sensor nodes sense and generate packets. These packets are forwarded towards the sink node. After a particular time, the power consumption speed of all the nodes in the network is compared with max. If any node having higher energy consumption speed, then a message with the location of the mobile node is forwarded to the sink node. The sink moves toward the intended node location. Some of the traffic at the intended node is forwarded via the mobile node. This reduces the traffic as well as the energy consumption speed of the intended node. The proposed (Algorithm 7) work on:

<table>
<thead>
<tr>
<th>Algorithm 7: Algorithm for mobile node scheme:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Require: Check ConsSpeed for all N;</td>
</tr>
<tr>
<td>2. Compare ConsSpeed with T;</td>
</tr>
<tr>
<td>3. if ConsSpeed &gt; T = d_n;</td>
</tr>
<tr>
<td>4. Set m_n = d_n;</td>
</tr>
<tr>
<td>5. Move m_n toward the location;</td>
</tr>
<tr>
<td>6. Repeat step 2 - 4;</td>
</tr>
</tbody>
</table>

1. To detect and reduce the congestion.
2. To control the node wise traffic flow.
3. To reduce packet loss ratio (PLR).
4. To increase the network lifetime.
5. To increase packet delivery ratio (PDR).
6. To increase throughput.
7. To balance the energy consumption of all nodes in the network.
8. To reduce energy consumption.
4.7 Results and Discussion

The proposed algorithm intends to minimize the power consumption by controlling the congestion in the network. This is achieved by tuning of energy consumption parameter which has substantial impact on total energy consumption. The various parameters considered as node density i.e. number of nodes in the system, RR - the number of packets transmitted every second, packets size, etc. The Table 4.3, shows the simulation parameters used for energy consumption. Simulation has been carried out using a powerful network simulator-2 (NS-2) to measure the performance of the proposed method. By varying these parameters, energy consumption in the network is noted. Figure 4.6 (a) shows the graph of total energy consumption on the node density. It has been observed that the energy consumption gradually increases as node density varied for 1 to 4 and suddenly rises as node density changes from 4 onwards. The same scenario is observed if we considered average energy consumption as shown in Figure 4.6 (b). Figure 4.6 (c) shows average energy consumption vs. packet size. It is to be noted that the average energy consumption is linearly varies for the packet size changes from 2 to 4 and thereafter it remains constant at 1.92 for packet size more than 4. Change in RR i.e. number of packets transmitted per second is also one of the factors which cause the variation in a rate of energy consumption. As the RR increases, the number of packets generated in the network also increases. To forward that number of packets, the network consumes more energy, the energy consumption increased. But after a particular point, the increase in RR increases the packet loss. The energy consumption gets reduced as shown in Figure 4.7 (a). By keeping all the simulation parameters same, and just varying the simulation time, the energy consumption is shown in the graph Figure 4.7 (b). The energy consumed is linear as the simulation time increases and is given by

\[ y = 0.170x + 0.183 \]

As the number of mobile nodes changes from 1 to 6, the fluctuations in the average energy consumption is observed as depicted in Figure 4.7 (c).

The Figure 4.8 shows the fairness index with varying mobile nodes. The fairness index for one mobile node is maxed than other cases as shown in Table 4.4. Therefore, for this work, only one mobile node is considered. To solve the congestion problem, an extra node is generated and moved to the intended location nearby the sender node concerned with congestion. This node known as mobile node which helps the sender node to forward the data to the intended receiver with congestion. This intended location is detected with the use of congestion detection algorithm and accordingly to the receivers capacity, an appropriate mobile node is generated.
Table 4.3: Experimental Setup

<table>
<thead>
<tr>
<th>Simulation parameters</th>
<th>Network area 500 x 500</th>
<th>Network area 1000 x 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topology</td>
<td>Random</td>
<td>Random</td>
</tr>
<tr>
<td>MAC protocol</td>
<td>802.11</td>
<td>802.11</td>
</tr>
<tr>
<td>Routing Protocol</td>
<td>AODV</td>
<td>AODV</td>
</tr>
<tr>
<td>Number of sensor nodes</td>
<td>50</td>
<td>26</td>
</tr>
<tr>
<td>Queue length</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Initial energy</td>
<td>2 Joules</td>
<td>2 Joules</td>
</tr>
<tr>
<td>Simulation time</td>
<td>50 sec</td>
<td>10 sec</td>
</tr>
<tr>
<td>Packet size</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>cbr start time</td>
<td>1.0 sec</td>
<td>1.0 sec</td>
</tr>
<tr>
<td>cbr stop time</td>
<td>49.0 sec</td>
<td>10.0 sec</td>
</tr>
<tr>
<td>Packet interval</td>
<td>0.1</td>
<td>0.025</td>
</tr>
<tr>
<td>Number of sink node</td>
<td>01</td>
<td>01</td>
</tr>
<tr>
<td>Position of sink node [(m,m)]</td>
<td>(500,500)</td>
<td>(800,800)</td>
</tr>
<tr>
<td>Radio signal range</td>
<td>15m</td>
<td>25m</td>
</tr>
<tr>
<td>Mobile sink velocity</td>
<td>5m/s</td>
<td>10m/s</td>
</tr>
<tr>
<td>Payload size of data packet</td>
<td>1000 Bytes</td>
<td>1000 Bytes</td>
</tr>
<tr>
<td>Channel Bandwidth</td>
<td>1 mbps</td>
<td>1 mbps</td>
</tr>
<tr>
<td>Transmission range</td>
<td>150m</td>
<td>250m</td>
</tr>
<tr>
<td>Sensing Range</td>
<td>90m</td>
<td>550m</td>
</tr>
<tr>
<td>Antenna type</td>
<td>OmniAntenna</td>
<td>OmniAntenna</td>
</tr>
<tr>
<td>Radio-propagation model</td>
<td>TwoRayGround</td>
<td>TwoRayGround</td>
</tr>
<tr>
<td>Interface queue type</td>
<td>Queue/DropTail/PriQueue</td>
<td>Queue/DropTail/PriQueue</td>
</tr>
<tr>
<td>Idle power</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>rxpower</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>txpower</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>Sleep power</td>
<td>0.000015</td>
<td>0.000015</td>
</tr>
</tbody>
</table>
Figure 4.6: (a) Total Energy Consumption Vs Node Density; (b) Average Energy Consumption Vs Node Density; (c) Average Energy Consumption Vs Packet Size.
Figure 4.7: (a) Average Energy Consumption Vs RR; (b) Average Energy Consumption Vs Simulation Time; (c) Average Energy Consumed Vs No. of Mobile Node.
The mobile nodes are placed nearby the sink node to avoid the loss of energy due to distance between two nodes. The simulation parameter mentioned above are used to compute the PDR, PLR, and throughput for the four different cases as:

- **Case 1**: Describes the basic scenario without congestion control and no use of mobile nodes.
- **Case 2**: Consisting of varying RR with congestion control mechanism.
- **Case 3**: Scenario with mobile nodes.
- **Case 4**: Consists of mobile nodes and congestion control mechanism.

All these four cases are elaborated in Figure 4.9. The PDR is found to be maximum in case of scenarios with congestion control mechanism. The scenarios with mobile nodes result in improved PDR than otherwise. The global scenario depicts that when the PLR increases, then PDR decreases. In the scenarios, the congestion control mechanism, and mobile node together improves the overall throughput of the network. Furthermore, energy consumption rate for four distinct cases are studied as:

- No control.
- Congestion.
- Mobile node.
- Mobile node + Congestion control.

and shown in Figure 4.10. The energy consumption rate is maximum in the no control scenario i.e. more energy is consumed in that case. This energy consumption rate is decreased with the use of congestion control algorithm. The rate of energy consumption is mostly reduced with the use of mobile nodes. The node which consumes the energy at the higher rate is likely to die earlier than other. Figure 4.11 depicts the speed of power consumption by each node. Without mobile nodes, the consumption speed variation is more than the use of mobile nodes. The use of mobile nodes somewhere balances the energy consumption speed. The node number 2 is having energy consumption speed more than other nodes. Therefore, when mobile nodes reach to the node 2, the energy consumption speed of node 2 gets decreased. Also, the energy consumption speed of all nodes is reduced. A lifetime of node 2 is increased with the help of mobile nodes. The Figure 4.12 shows the graph of a lifetime of the intended node i.e. node 2, which confirms the usefulness of the proposed method.
Table 4.4: Results of Fairness Index with Varying Number of Mobile Nodes

<table>
<thead>
<tr>
<th>Number of Mobile Nodes</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Energy Consumed</td>
<td>0.8607</td>
<td>0.7722</td>
<td>0.8128</td>
<td>0.7670</td>
<td>0.8288</td>
<td>0.8609</td>
</tr>
<tr>
<td>Fairness Index</td>
<td>0.9986</td>
<td>0.9989</td>
<td>0.9982</td>
<td>0.9983</td>
<td>0.9983</td>
<td>0.9987</td>
</tr>
</tbody>
</table>

Figure 4.8: Fairness Index Vs No. of Mobile Nodes

Figure 4.9: PDR, PLR, Throughput for 4 Distinct Test Cases
Figure 4.10: Rate of Energy Consumption in 4 Distinct Test Cases

Figure 4.11: Energy Consumption Speed of Each Node

Figure 4.12: Lifetime of the Intended Node
4.8 Conclusion

The real strength of AFRC algorithm is further investigated to leverage its potential benefits in this proposed work. This novel strategy presented here demonstrates the use of mobile nodes for effective congestion control as well as reducing energy consumption in the network. For evaluation purpose, we have performed simulation analysis using NS-2 and shows the results are as follows.

Using the congestion control scheme, the PDR increased by 44.80%, PLR decreased by 83.19% and the throughput increased by 44.80%. The mobile nodes in the network, the energy consumption rate decreased by 53.4%, and the lifetime of a node increased by 5.52%. Also, the PDR increased by 29.27%, PLR decreased by 89.02% and the throughput increased by 29.15%. 