MCDR: Mitigating Congestion using Distance based Routing in Wireless Sensor Networks

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Abstract: *The network performance in WSNs is mainly affected by the congestion due to bursty traffic. Congestion can cause large packet drops, increased energy consumption and latency. Different traffic rate control mechanisms have proposed to mitigate congestion and most of these mechanisms are greatly affecting the fidelity requirement of the applications. In this paper, we proposed an algorithm named, Mitigating Congestion using Distance based Routing (MCDR) technique to mitigate congestion. This technique has successfully reduced congestion by scattering the traffic through the nodes which are placed at comparatively minimum distance from the sink and whose Queue Length is below the threshold value. The Residual Energy and Depth are two added parameters to strengthen the scattering decision. Simulation results shows that the network throughput has significantly improved with minimized latency due to the reduction of loops when compared to previous works.*
Keywords: *Congestion, Distance based routing, Wireless Sensor Networks (WSNs), Residual Energy*

I. Introduction

The scarce resources in WSNs are affected by many factors and degrade the network performance. Congestion is one of the major factors that affect the overall network performance, due to bursty traffic. The applications in WSNs can cause the congestion around the sinks due to centralized traffic pattern. The event driven applications in WSNs produce variable traffic rates in the network and hence it is necessary to maintain fair rate transmission. Rate control and traffic scattering are the most common approaches used to minimize congestion. Although, some of the problems like end-to-end delay, high energy consumption and information processing overheads still exist in the network due to congestion.

Congestion can exist in a network at two different levels *viz;* the node level and the link level. Node level congestion is due to the buffer overflow and causes the packet loss while link level congestion is due to the contention among the multiple nodes for the transmission medium and degrades the link utilization.. Some of the important and relevant approaches to alleviate congestion are discussed below.

The precedence based data forwarding is one of the approaches that can minimize the congestion. In this approach the high precedence data is forwarded first and low precedence data will be considered next [11]. Precedence based data forwarding can highly penalize the low priority data applications.

Adaptive resource control is one of the congestion control mechanism that dynamically provide the required resource capacity to handle different traffic rate levels [12]. The dynamic provisioning of resource results in managerial overheads in keeping track of the status of the traffic level. The Congestion Detection and Avoidance (CODA) [13] technique is one of the popular approaches to mitigate congestion. It is an upstream mitigation mechanism that uses the queue length of the node and present load on the link to detect congestion. But, the CODA insists on strict transmission policy to acknowledge each packet between the intermediate nodes on the transmission path from source to sink, which increases the end-to-end delay.

The Event to Sink Reliable Transport protocols [14] are developed to achieve event level reliability from source to sink by controlling the congestion in the network. This protocol performs the end-to-end source rate adjustment based on the requirement of reliability level at the base station. There are several mechanisms that performs congestion control by minimizing the hop-by-hop congestion [15][16][1][2][17]. Some of the algorithms detect the congestion based on the rate of channel contention, size of the buffer and hop count [3]. The congestion ratio, packet sender ratio and congestion degree are considered to detect congestion in network [18] [19].

1.1 **Motivation:**

Congestion in a wireless sensor network is one of the critical issues that has to be addressed to improve the network throughput and performance. Most of the previous works attempt to mitigate congestion by rate control, adaptive resource provisioning and scattering traffic through multipath and under loaded nodes. Congestion control mechanisms in all these works are developed mainly based on the parameters like queue length, the packet loss ratio, and depth and energy consumption. In our work we have considered the distance of the nodes along with the queue length, residual energy and depth of each node. This mechanism is illustrated by using an example shown in Fig. 1 and Fig. 2.

Let a bursty of traffic be generated at node A and node Y and the adjacent node B is selected to forward the traffic towards the sink through the single path as shown in Fig. 1. It causes congestion at node B and delay the packet transmission towards the sink thereby lowering the network throughput. Hence, it is necessary to mitigate congestion at node B, by choosing multiple paths *via* lightly loaded nodes. Fig. 2 illustrates the traffic scattering through the multiple paths from node Y to sink *via* lightly loaded node U and from node A to sink *via* lightly loaded node B. Here, both the node U and node B are placed comparatively at minimum distance to the sink. This mechanism also effectively minimizes the looping problem decreases the Latency and increases the network throughput and minimizes the energy consumption.
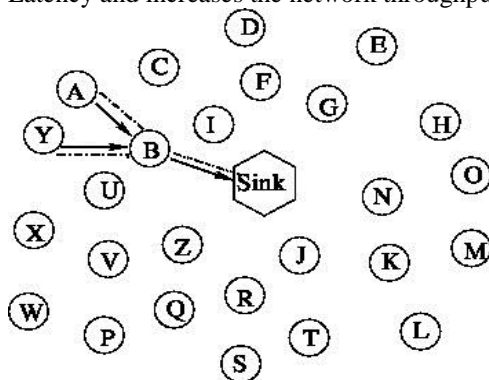

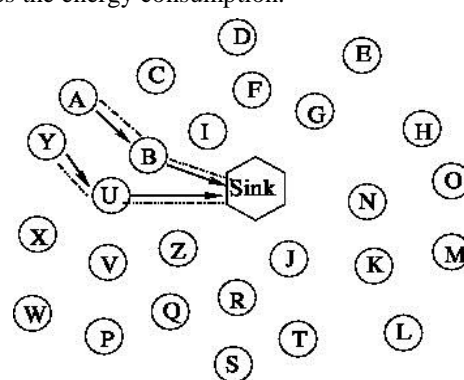
Figure1- Congestion due to single path and Congested node.

Figure 2 – Congestion Mitigation by Scattering the traffic through multiple path and lightly loaded nodes.

1.2 **Contribution:**

The design of our algorithm mainly considers the distance parameter while scattering the traffic through the nodes in the congested area. The queue length, the hop count, residual energy are the additional parameters used along with the distance. The decision of scattering of traffic towards sink based on these parameters effectively reduces energy consumption, looping problems and maximizes the overall network throughput of the network.

1.3 **Organization:**

The rest of the paper is organized as follows. Section 2 presents a brief literature of related works. Section 3 discusses the background work, while section 4 defines the problem and objectives. Section 5 describes the system and mathematical model and proposed algorithm. Section 6 presents the performance evaluation. The concluding remarks are summarized in section 7.

II.   Literature survey

This section presents a brief summary of related works.

Shigang et al., [4] proposed a congestion avoidance scheme based on light weight buffer management. It prevents data packets from overflowing the buffer space of the intermediate sensors. This approach makes sensors to accustom for optimal forwarding rates without creating the congestion. It is also extended with different MAC protocols, especially for CSMA with implicit ACK, and the 1/k buffer solution prevents hidden terminal from causing congestion. This work illustrates the maintenance of near optimal throughput with minimum buffer size at each sensor and congestion free load balancing for multiple routing paths towards multiple sink. Even though the congestion is effectively alleviated, it affects the fidelity of the applications.

Kang et al., [5] presented a Topology-Aware Resource Adaptation (TARA) algorithm to alleviate congestion. A capacity analysis model is presented that can be used to estimate capacity of different topologies. The careful consideration of type of congestion traffic pattern and network topology is adapted for the use of resource control. This algorithm achieves higher level of data delivery rate and minimized energy consumption when compared to ideal offline resource control algorithm. The resource capacity estimation is a graphic-theoretic

approach that requires both local knowledge and knowledge about the end-to-end topology. The time overhead is too high for dense networks.

Kumar et al., [6] addressed differentiated data delivery in wireless sensor networks for congested environment. Two algorithms enforce the differentiated routing based on congested area of the network and data priority. The basic protocol Congestion-Aware Routing (CAR) finds the congested zone of the network that is present between high priority data sources and data sink and reserves this area to forward high priority data traffic. Medium Access Control-enhanced CAR (MCAR) is another protocol which is designed to handle the mobility of high priority data sources that cannot be handled by CAR. This scheme gives less importance for low priority traffic, which affects the overall throughput of the network.

Neal et al., [7] implemented relative location estimation algorithms in a WSNs testbed deployed in indoor and outdoor environments. These algorithms are designed, based on a general class of estimation problem known as Cramer-Rao Bound (CRB). The main objective of these algorithms is to show the accuracy with which WSNs can estimate the relative sensor locations. This scheme needs to verify the variance of location estimators due to the non-ergodic nature of shadowing.

Jenn et al., [8] developed a technique to evaluate the quality of path set for multipath load balancing in the presence of wireless interferences. In addition, there are two schemes such as Interference minimized Multipath Routing (I2MR) protocol to increase the throughput by discovering zone-disjoint paths for load balancing. The second one is congestion control scheme that further increases throughput by loading the paths for the load balancing at the highest possible rate supportable. This protocol needs to consider suitably spaced deployment for source-destination pairs and observed the effect of interpath set interferences.

Wang et al., [9] developed upstream congestion control protocol for WSNs, called Priority based Congestion Control Protocol (PCCP). It effectively measures the congestion degree as the ratio of inter-arrival time along over packet service time. Here, the congestion control follows hop-by-hop approach that utilizes the cross layer optimization based on congestion degree and node priority index. PCCP achieves the better congestion control using flexible weighted fairness for both single path and multipath routing. It is also minimizes packet loss rate, the delay and enhanced energy efficiency.

Fengyuan et al., [10] presented the Traffic Aware Dynamic Routing (TADR) protocol to route the packets around the congested areas and divert the overloaded packets along with multiple paths consists of the idle and under loaded nodes. This algorithm uses a hybrid virtual potential field using depth and queue length to divert the packet towards the sink. This scheme improves the fidelity level required by the applications. The TADR does not support delay sensitive and high integrity applications.

Wan et al., [13] proposed a congestion control scheme called, CODA (Congestion Detection and Avoidance). This framework is designed for CSMA based sensors and this congestion control scheme includes three key mechanisms such as receiver based congestion detection, open loop hop-by-hop back pressure and closed loop multi source regulation. The CODA improves the performance of directed diffusion significantly by reducing the average energy tax with minimal fidelity penalty. This work has not been tested for large scale networks.

Yogesh et al., [14] address the notion of sink reliability notion rather than End-to-End reliability. The notion of event to sink reliability is necessary for reliable transport of event features in WSNs. That is because the sink is always interested in collective information of source nodes rather than individual nodes. This idea is implemented through Event Sink Reliable Transport (ESRT) protocol. It achieves the reliable event detection with minimum energy consumption and congestion resolution. The ESRT addresses only the single event in a network, so that it is necessary to check with multiple concurrent events to investigate other possible reliability metrics. It does not support end-to-end reliable data delivery.

Mohammad et al., [15] designed congestion avoidance and fairness algorithms for WSNs. The numerous sensors transmit data to the base station and it increases the probability of packet drops due to congestion close to the base station. This algorithm uses the ratio of the number of downstream and upstream nodes to detect early status of the congestion. Monitoring queue sizes of candidate downstream nodes help to ensure effective load balancing and fairness in this algorithm, hence, it increases the packet delivery ratio and network lifetime. This approach is designed only for the static network topology.

Tian et al., [17] developed a real-time communication protocol for sensor networks. The End-to-End Delay depends on single-hop delay and the distance covered by the packets. SPEED protocol supports a soft-real time communication with a desired delivery speed, so that End-to-End Delay is proportional to the distance between the source and destination. It improves the End-to-End Delay and alleviates congestion. Extensive monitoring of information is required for soft real-time communication that drains out energy quickly.

Wan et al., [19] addressed the problem of funnelling effect in many to one multi hop traffic pattern which characterizes the sensor networks communications. This problem can be overcome by exploiting the available wireless and multi radio virtual sinks that can be randomly deployed or placed at selective positions across the networks. These virtual sinks siphon off the data effectively from the congested area in a network. It

can scale the networks by managing increased traffic demands with minimum impact on application fidelity. The deployment of virtual sinks in a network requires the selection of specific positioning mechanism for effective siphoning off the data for congestion control.

Basu et al., [20] presented a routing paradigm called Potential-Based routing (PB-routing), that is based on gradient search methods to route data packets. The algorithm assigns a scalar potential to network elements, transmits the packets in the direction of maximum positive force and the routing schemes are free from the loops. This algorithm also presents the design of potential function that accounts for traffic condition at a node and the resulting routing algorithm routes around congested areas while preserving the important properties of IP routing mechanisms. It shows significant improvements in end-to-end delay and jitter when compared to previous shortest path routing algorithms. It involves huge management overhead and also explosive to build an exclusive virtual field for every destination in a network.

Hull et al., [21] examined three techniques for mitigating congestion: hop-by-hop flow control, limiting source rate and prioritized Medium Access Control (MAC). The combinations of these three techniques are known as Fusion. Fusion avoids Congestion and improves network efficiency. The rate limiting technique at the each node introduces the monitoring overheads to observe their parent's sending actions to determine the time to generate tokens. This process consumes a large amount of energy.

Kang et al., [22] developed an adaptive resource control scheme to alleviate congestion in resource networks. Here, the dynamic resource provisioning has done based on the capacity level. Congestion alleviation is carried out either by increasing the number of nodes or by providing more routing paths. Resources can also be reduced, when there is no congestion in the network to save energy consumption. It is expensive to control the resource availability and accuracy level required by applications.

Jeongyeup et al., [23] discussed a Rate Control Reliable Transport (RCRT) protocol for constrained sensor nodes in WSNs. It places its congestion control functionality at the sink, so that it enables better aggregate control of traffic and provides flexibility in rate allocation. The RCRT's rates are significantly higher than that of state-of-art in sensor network's congestion control. This protocol is less efficient in co-ordinating the rate allocation across the sinks and it has to improve the convergence time in networks with highly varying Round Trip Time (RTT).

Aris et al., [24] conducted a survey on routing algorithms and identified the requirements and properties that need to be address. The authors addressed possible approaches in the design of efficient routing algorithms for Ad-Hoc sensor networks. Peter et al., [25] analysed and compare reactive single path and multipath routing with load balancing mechanism in ad-hoc networks. The result shows that multipath routing mechanisms create more overhead but provides better performance in congestion and capacity within certain upper bound value of route length. It is found that the performance of multipath routing mechanism decreases above the upper bound value of route length.

Lucian et al., [26] proposed a solution for the betterment of throughput and fairness in wireless networks. This approach has designed with three protocols, namely Biased Geographical Routing (BGR), In network Packet Scatter (IPS) and End-to-end Packet Scatter (EPS). The BGR is one of the multipath routing protocol and IPS, EPS are the two congestion control protocols. The transient congestion and long term congestion alleviates successfully by these protocols and exhibit the simplicity and low communication overhead. This protocol requires large testbed to test EPS and IPS in practice.

Sumit et al., [27] introduced Interference aware Fair Rate Control (IFRC) mechanism to dynamically allocate the fair and efficient transmission rate to each node. It detects the congestion level at each node based on the average queue length and maintained fair and efficient rate. Here the queue overflow is completely avoided and it results in highly effective rate adaptation mechanism. It can be extended easily to support multiple base stations in a network. The end-to-end reliability that is required for the complete validation and analysis of all parameters of IFRC, has not completely provided by this protocol.

Yaghmaee et al., [28] presented a priority based rate control mechanism for congestion control and service differentiation in Wireless Multi Media Sensor Networks (WMSNs). This protocol clearly differentiates the high priority real time traffic from low priority non-real time traffic. It regulates the source traffic rate based on the status of congestion in the upstream nodes and priority of each traffic source. This protocol provides low packet loss probability, low queuing delay and guaranteed bandwidth for high priority real time traffic. The low priority traffic sources suffers from high latency and low reliability.

In the proposed protocol, we have devised an efficient method of congestion control mechanism that mainly considers the distance parameter along with the queue length, depth and residual energy of each node when scattering the traffic towards the sink at the point of congestion. This mechanism minimizes the distance between the source nodes and the sink, looping problem and maximizes the throughput of the network.

III.   Background

Most of the existing congestion control protocols mitigate congestion by controlling the traffic rate at the node level. The traffic rate control scheme always minimizes the throughput and brings down the fidelity level required by the application. In order to overcome this problem, the Traffic Aware Dynamic Routing (TADR) protocol is designed to route the packets around the congested areas and divert the overloaded packets along with multiple paths consisting of the idle and under loaded nodes [10]. This algorithm uses a hybrid virtual potential field using depth and queue length to divert the packet towards the sink. The TADR does not support delay sensitive and high integrity applications due to high End-to-End Delay.

 Our work mitigates congestion by scattering the traffic, based on the parameters such as the distance, the normalized queue length, depth and the residual energy. The proposed algorithm has effectively increases the throughput and minimizes energy consumption. The end-to-end delay is drastically reduced due to elimination loops.

IV.   Problem definition

In a given wireless sensor network of *N* randomly deployed nodes, the bursty traffic causes congestion due to high data rate applications. Congestion is mitigated by scattering the packets through the node N_i, where the value of *i* varies from *1 to n* on the path followed by the packets to the sink. The nodes are selected, based on the status of the queue length Q_l, depth *d*, the residual energy R_e and the distance *D* to the sink. The main objectives of our research work are:

(1) To improve the network throughput by implementing distance based congestion control.
(2) Reduction of the loops to minimize the Latency.

Assumptions:
(1) Initially all the sensor nodes have equal residual energy and queue length is zero.
(2) The sink consists of highest energy and located at the centre of the network.

V.   System and mathematical model

The proposed model for Mitigating Congestion using Distance based Routing (MCDR) protocol is illustrated as shown in the Fig. 3.

The system architecture is divided into six different phases. The first phase involves the monitoring of event generation and traffic status. If the nodes are found to be congested, it is necessary to scatter the traffic/packets through the lightly loaded nodes along the multiple paths. This process is carried out in second phase. The third
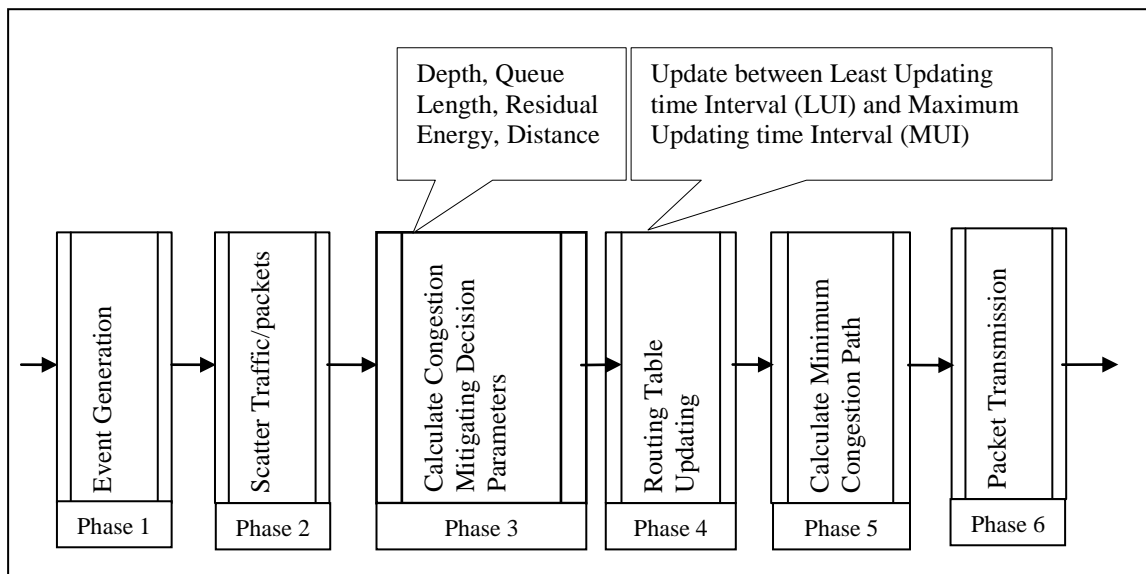

Figure 3 – Proposed model for MCDR protocol

phase involves the calculation of congestion mitigating decision parameters such as depth, queue length, residual energy and the distance to select an appropriate neighbour node. The fourth phase generates the updated routing table values between the Maximum Updating Interval (MUI) and Least Updating Interval (LUI). The fifth phase involves the computation of minimum congestion path based on the congestion mitigating decision parameters. The sixth phase represents the packet transmission towards the sink.

5.1 Congestion mitigating decision parameters

This phase involves the calculation of congestion mitigating decision parameters, such as depth, residual energy, queue length and distance to the sink for each node. These parameters are explained below.

5.1.1 Depth

The depth, *d* of a node is defined as the total number of hop counts between itself and the sink. Initially, the sink initializes its own depth, *d* as *d = 0*, and broadcasts this value to its immediate neighbour nodes. Then, the neighbour nodes updates its depth as, *d = d + 1*. This process is repeated until all the nodes compute their depth *d* to the sink.

5.1.2 Residual Energy

The Residual Energy, is defined as the energy retained in each node after the previous receiving and transmission process. The Residual Energy R_e can be computed as:

$$R_e = I_e - (E_t + E_r), \tag{1}$$

where, I_e is the Initial Energy, E_t and E_r are the energy required for Transmission and Receiving respectively. The energy for transmission E_t is the energy required to transmit each packet and computed as:

$$E_t = P_t + T_t, \tag{2}$$

where, P_t is the number of packets transmitted and T_t is the time required to transmit each packet. The Receiving Energy R_e is the energy required to receive each packet. This can be computed as:

$$E_r = P_r + T_t, \tag{3}$$

where, P_r is the number of packets received, T_t is the time required to receive each packet.

5.1.3 Queue length

The Queue Length, Q_l is defined as the ratio of number of packets in the buffer to the maximum buffer size of the node. It can be calculated as

$$Q_l(i) = \frac{N_p}{B_s(i)} \tag{4}$$

where $Q_l(i)$ is the Queue Length of *node i*, N_p is the number of packets in the buffer, $B_s(i)$ is the maximum buffer size of *node i*.

5.1.4 Distance

The Distance between the nodes to the sink can be calculated using Euclidean distance formula. The distance $D(i,j)$ is represented as:

$$D(i,j) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{5}$$

where $D(i,j)$ is the distance between the *node i* and *sink node j*, (x_1, x_2) is the *x* co-ordinates of *node i* and *sink node j* and (y_1, y_2) is the *y* co-ordinates of *node i* and *sink node j*.

5.2 Routing table updation

In the network, every node consists of the routing table, which stores the updated values of congestion mitigation decision parameters. The routing table updation is carried out four different events. In the first event, the normal routing table updation is done between the Least Updating time Interval (LUI) and Maximum Updating time Interval (MUI). Routing table updation occurs at the expiry of both MUI and LUI(second event). The third event involves routing table updation, when depth changes and LUI expires. The fourth event updates routing table when the queue length exceeds the queue threshold value and LUI expires. The complete routing table updation algorithm is presented in Table I.

Table I. Routing Table Updation Algorithm

Algorithm 1 Routing Table Updation Algorithm
input : LUI, MUI, time, depth, Q_l, $Q_{threshold}$
   Routing_Table_Updation( )
     messagePending = false
     if *time >= LUI* **&&** *time < MUI* **then**
     updateTable( )
     else if *time > MUI* **&&** *time > LUI* **then**
      updateTable( )
     else if *d varies* **&&** *time > LUI* **then**
      updateTable( )
     else if *Q_l > $Q_{threshold}$* **&&** *time > LUI* **then**
      updateTable( )
     else
      messagePending = true
     end if

5.3 Computation of minimum congestion path

The fifth phase computes the minimum congestion path based on the values of congestion mitigating decision parameters. This computation is based on the updated values of the routing table that enables to select the feasible neighbour with the queue length below the threshold value, maximum residual energy, minimum depth and minimum distance from the sink. If these conditions are not met, the next neighbour node is selected. This process is repeated until the minimum congestion path towards the sink is established. The algorithm is given in Table II.

Table II. Mitigating Congestion using Distance based Routing (MCDR) Algorithm

Algorithm 2 MCDR Algorithm
Input : $Q_{threshold}$
  Step 1 : Calculate Congestion Mitigating Decision Parameters.
    for each *node in a network* **do**
     Calculate d
     Calculate R_e
     Calculate D
     Calculate Q_l
    end for
  Step 2 : Routing Table Updation
    Routing_Table_Updation( )
  Step 3 : Calculate Minimum Congestion Path
    for each *neighbour node* **do**
     if *Q_l < $Q_{threshold}$* **&&** *max R_e* **&&** *min d* **&&** *min D* **then**
     sendMessage( )
     else if *Q_l > $Q_{threshold}$* **then**
      select next node
     end if
    end for
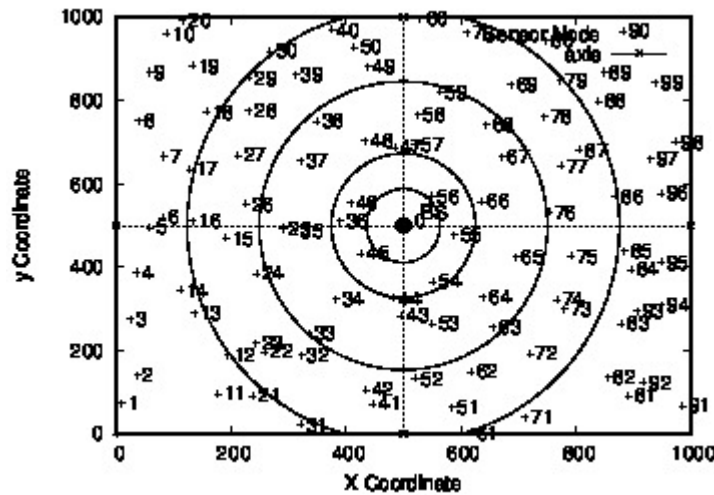 **Step 6 :** Repeat above step until packet reaches sink.

Figure 4 – Sensor Node Distribution

6.1 Performance metrics
The following performance metrics are used to analyse the MCDR algorithm.
(a) **Network Throughput Rate (NTR)**: It is defined as the number of packets received per unit of time by the sink from different source nodes.
(b) *Packet Delivery Ratio (PDR)*: It is the ratio of actual packet received by the sink to the total number of packets sent from the source.
(c) **Latency:** It is the total time required to transmit each packet from the source to the destination.
(d) **Network Congestion Rate (NCR):** It is defined as the average number of packets queued up at each node per unit of time in a network.

6.2 Performance analysis
Table III depicts the Network Size, the Number of nodes deployed, Node Distribution, Initial Energy, Location and Simulation time.

Table IV shows the Network Throughput Rate for the proposed protocol MCDR in comparison with TADR. Fig. 5 illustrates the comparative value of Network Throughput with our protocol MCDR and TADR. This graph illustrates the throughput level of two protocols, MCDR and TADR. MCDR exhibit the better throughput rate for both normal and bursty traffic rate. It is observed that the time between 0 to 4s and 7 to 12s in normal situations and between 4 to 7s and 12 to 14s of bursty traffic, the MCDR shows high throughput rate compared to TADR.

Table III –Simulation Parameters

Parameter	Values
Network Size	1000m * 1000m
Number of nodes	100
Node Distribution	Random
Initial Energy	10J
Data Packet Size	1024
Sink Location	500m * 500m
Simulation time	2000s

Table IV – Network Throughput Rate

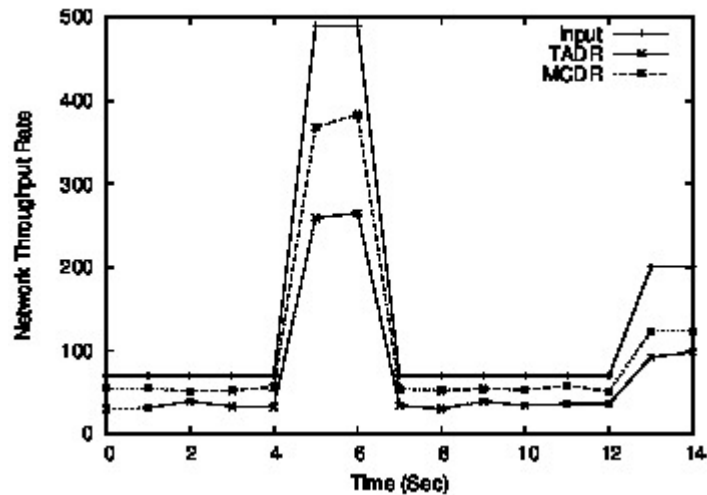| Simulation Time	Network Throughput Rate		
	Input	MCDR	TADR
0	50	45	30
1	50	45	31
2	50	41	39
3	50	42	33
4	50	46	32
5	490	368	259
6	50	383	265
7	50	44	34
8	50	42	30
9	50	44	39
10	50	43	34
11	50	48	36
12	50	41	36
13	200	123	92
14	200	123	98

Figure 5 – Network Throughput Rate

This is due to minimized packet drops on account of the balanced Queue Length at each node in the network. The balanced queue length is achieved by the considering the distance of each node to the sink while scattering the traffic towards the sink. It is observed that the network throughput has increased by 62.5% over the earlier protocol TADR.

Table V shows the packet delivery rate for both at high load and low load condition in the network for MCDR and TADR. Fig. 6 and Fig. 7 illustrate the graphical representation of these values. It is observed in Fig. 6 that both MCDR and TADR shows almost same packet delivery rate when network generates lower number of packets (between 1 to 4s). MCDR exhibits higher packet delivery rate when compared to TADR while the network generates higher number of packets.

It is observed that in Fig. 7 that the packet delivery rate for TADR starts from lower packet delivery rate and increases with minimum value over the time (1 to 12s) and does not exceed more than 32 packets in average per second. Whereas, MCDR starts with comparatively higher packet delivery rate and increases linearly over the time (1 to 12s) and delivers 82 packets in average per second. Thus, MCDR exhibits better Packet Delivery Rate at both high and low load conditions. It is about 46.5% higher for high load condition and 37.5% higher for low-

Table V – Comparison values of Packet Delivery Rate for Low and High Load and Latency

Simulation Time	Number of Packets Delivered at Low Load			Number of Packets Delivered at High Load			Latency	
	Input	MCDR	TADR	Input	MCDR	TADR	MCDR	TADR
1	4.5	2	2	140	80	20	10	12
2	10	6	4	110	60	50	11	16
3	10	7	6	110	70	30	11	18
4	16	14	10	120	80	25	11	18
5	24	20	14	125	90	20	12	24
6	24	21	14	125	85	40	12	26
7	24	21	14	125	75	30	12	18
8	25	21	14	125	80	35	12	15
9	21	16	10	125	85	45	11	11
10	18	12	6	115	90	10	11	18
11	15	12	6	110	95	33	11	14
12	15	8	4	110	95	38	11	14

load condition over the performance of TADR. This increased performance is due to the greater loop reduction and scattering of traffic through the nodes which are placed at minimum distance to the sink in the network.

The Latency is depicted in Fig. 8 and the comparison values are tabulated in Table V. It is observed that the MCDR exhibits highly reduced Latency for both normal (1 to 4s and 9 to 12s) and bursty traffic (3 to 8s). Whereas, the TADR exhibits high Latency for both normal and bursty traffic (1 to 12s). Thus, there is tremendous decrease in Latency of about 76.5% in MCDR when compared to TADR. This is due to cumulative

effect of the parameters in consideration *viz;* minimum depth, maximum residual energy and Queue Length within the Threshold value of each node during traffic scattering.

Table VI lists with the number of packets delivered to the sink through different number of hops in MCDR and TADR. Fig. 9 shows that the MCDR exhibits higher rate of packet delivery through both minimum and maximum number of intermediate hops compared to the TADR. It is observed that the packet delivery rate is decreasing in TADR with increased number of hops (between the range of 30 to 90 hop distribution). Our protocol MCDR maintain better packet delivery rate irrespective of number of hops due to the fair queue length maintenance and minimum congestion rate at each node.
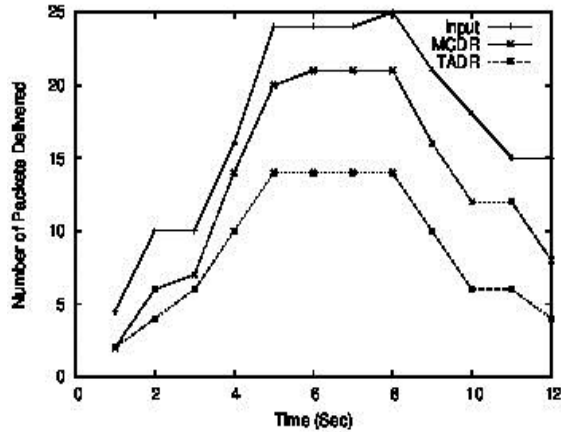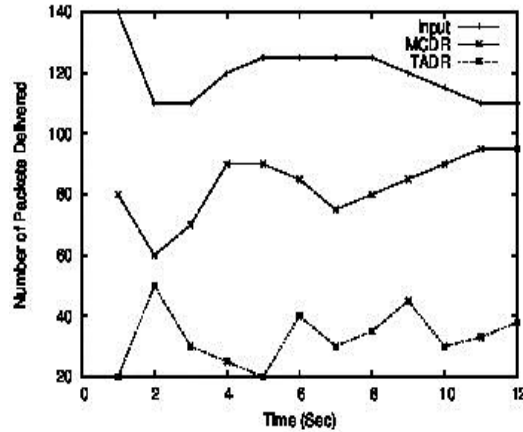

Figure 6 – Packet Delivery Rate at Low Load
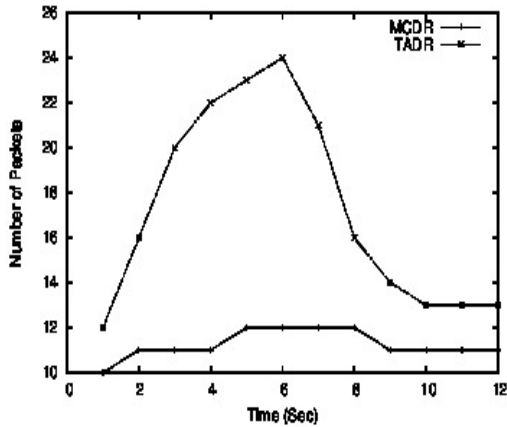

Figure 7 – Packet Delivery Rate at High Load

Figure - 8 Latency

Figure – 9 Hop Distributions
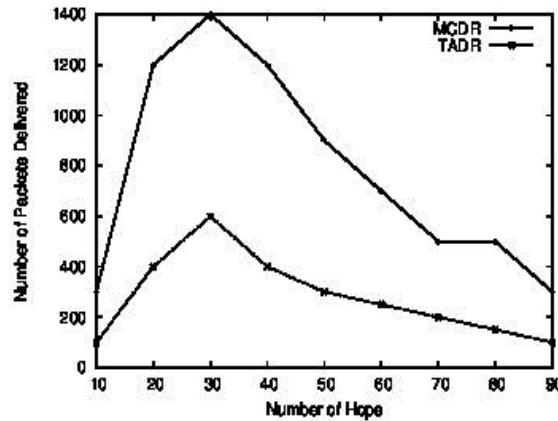
Table VI – Hop Distributions

Number of Hops	Number of Packets Delivered	
	MCDR	TADR
10	300	100
20	1200	1000
30	1400	1200
40	1200	1000
50	900	700
60	700	500
70	500	400
80	500	300
90	300	100

VI. Conclusions

Congestion mitigation is one of the major issues in WSNs due to scarce resources. Thus, it is necessary to maximize the utilization of these resources to improve the overall network performance. In WSNs, congestion mainly affects the network throughput and in turn, it sluggishes the network performance. Our proposed algorithm MCDR effectively mitigates congestion by considering the parameters such as minimum Queue Length, the depth, the distance and maximum residual energy of each node while scattering the traffic

towards the sink from the congested area. Improved network throughput is achieved by maintaining the minimum Congestion Rate due to fair Queue Length at each node in the network. The looping problem has been drastically reduced by selection of each node that is based on the minimum distance to scatter the traffic towards the sink. The reduction in looping results in lower Latency and minimizes energy utilization. The results of our proposed algorithm shows that improved network throughput and packet delivery rate for both high and low load conditions and also fulfils the fidelity requirement of different applications. Further, this work can be extended to support fidelity requirements of strict delay sensitive applications.

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