# CADR: Congestion Alleviation using Distance based Routing in Wireless Sensor Networks

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# CADR: Congestion Alleviation using Distance based Routing in Wireless Sensor Networks

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**Abstract**

Congestion degrades the overall network performance in WSNs and it can minimize the throughput of the network due to the large packet drop, increased energy consumption and end-to-end delay. Even though most of the proposed congestion control schemes reduce traffic rate, they affect the fidelity level required by the applications. In this paper, we propose an algorithm Congestion Alleviation using Distance based Routing (CADR) technique, where the bursty traffic is diverted towards the sink via the nodes whose queue length is below the threshold and is at minimum distance from the sink. The residual energy and the depth of the nodes are additional parameters which supports congestion mitigation. Simulation results show that the overall throughput of the network has tremendously improves for large and dense wireless sensor networks when compared to the earlier works.

*Keywords:* Congestion, Distance based routing, Wireless Sensor Networks (WSNs), Residual Energy.

## 1. 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 burstyy 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.

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 [1]. Precedence based data forwarding can highly penalize the low priority data applications.

Adaptive resource control is one of the congestion control mechanism that dynamically provides the required resource capacity to handle different traffic rate levels [2]. 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) [3] 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 the 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.

***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.

***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.

***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.

## 2. Related Works

This section presents a brief summary of related works. Wan et al., [3] proposed a congestion control scheme called, CODA (Congestion Detection and Avoidance). 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., [4] 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. 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., [5] designed congestion avoidance and fairness algorithms for WSNs. This algorithm uses the ratio of the number of downstream and upstream nodes to detect early status of the congestion. This approach is designed only for the static network topology.

Tian et al., [6] developed a real-time communication protocol for sensor networks. 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., [7] addressed the problem of funnelling effect in many to one multi hop traffic pattern which characterizes the sensor networks communications. The deployment of virtual sinks in a network requires the selection of specific positioning mechanism for effective siphoning off the data for congestion control.

Shigang et al., [8] proposed a congestion avoidance scheme based on light weight buffer management. 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. Even though the congestion is effectively alleviated, it affects the fidelity of the applications.

Hull et al., [9] examined three techniques for mitigating congestion: hop-by-hop flow control, limiting source rate and prioritized Medium Access Control (MAC). This process consumes a large amount of energy.

Yaghmaee et al., [10] 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. 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.

## 3. 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 [11]. 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.

## 4. Problem Definition

In a given wireless sensor network of $N$ randomly deployed nodes, the bursty traffic causes congestion due to high data rate applications. The 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 end-to-end delay.

***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.

## 5. System and Mathematical Model

The proposed model for Mitigating Congestion using Distance based Routing (CADR) protocol is illustrated as shown in the Fig. 1. 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 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.

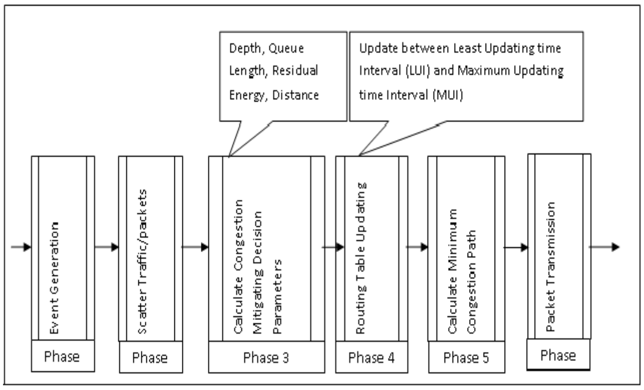


Figure 1: Proposed Model for CADR Protocol

### *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.

***(a) Depth***

The depth field, $d$ 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 neighbor nodes. Then, the neighbor nodes updates its depth as,

$d = d + 1$.

This process is repeated until all the cluster heads computes their depth $d$ to the sink.

***(b) 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:

$$R_e = I_e - (E_t + E_r) \quad (1)$$

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:

$$E_t = P_t \times T_t \quad (2)$$

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 and computed as:

$$E_r = P_r \times T_t \quad (3)$$

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

***(c) 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

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

where is the Queue Length of node $i$, is the number of packets in the buffer, $B_s$ is the maximum buffer size of node $i$.

***(d) Distance***

The Distance between the nodes to the sink can be calculated using Euclidean distance formula. The distance is represented as:

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

where 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 is presented in Algorithm 1.

**Algorithm 1** Routing Table Updation

**input** : $LUI, MUI, time, depth, Q_L, Q_{threshold}$
$Routing\_Table\_Updation(\ )$
$messagePending = false$
**if** $time \geq LUI\ \&\&\ time < MUI$ **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. This is given in Algorithm 2.

## 6. Simulation and Performance Analysis

The CADR protocol is simulated using NS-3 Simulator. Simulation results in terms of End-to-End Delay, Receiving Packet Rate and Throughput are illustrated in the following section. Our simulation set up includes 100 sensor nodes which are distributed randomly and deployed over the area 1000 * 1000 meters.

### *6.1.* ***Performance Metrics***

The following performance metrics are used to analyse the CADR 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) End-to-End Delay (EED)***: It is the total time required to transmit each packet from the source to the destination.
***(c) 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.

**Algorithm 2** Congestion Alleviation using Distance Based Routing (CADR) 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 neighbor node* **do**
  **if** $Q_l > Q_{threshold}$&& $maxR_e$ && $mind$ && $minD$ **then**
    *sendMessage*( )
  **else if** $Q_l > Q_{threshold}$ **then**
    select next node
  **end if**
**end for**

**Step 4 :** *Repeat above step until all the packets reaches sink*

Table 1: **Simulation Parameters**

| *Parameter* | *Values* |
|---|---|
| *Network size* | 1000$m$ x 1000$m$ |
| *Number of nodes* | 100 |
| *Node distribution* | *Random* |
| *Initial energy* | 10$J$ |
| *Data packet size* | 1024 |
| *Location of sink node* | 500$m$ × 500$m$ |
| *Simulation Time* | 20000 *seconds* |

### *6.2.* ***Performance Evaluation***

Table 1 depicts the Network Size, the Number of nodes deployed, Node Distribution, Initial Energy, Location and Simulation time. Table 2 shows the Network Throughput Rate for the proposed protocol CADR in comparison with TADR. Fig. 2 illustrates the comparative value of Network Throughput with our protocol CADR and TADR. This graph illustrates the throughput level of two protocols, CADR and TADR. CADR 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 burstyy traffic, the CADR shows high throughput rate compared to TADR. 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 2: **Comparison values of Network Throughput Rate and Latency for CADR and TADR**

| $Simulaton$ | $Network\ Throughput\ Rate$ | | | $End-to-End\ Delay$ | |
|---|---|---|---|---|---|
| $Time(mSecs)$ | $Input$ | $CADR$ | $TADR$ | $CADR$ | $TADR$ |
| 2 | 50 | 41 | 39 | 10 | 11 |
| 4 | 50 | 46 | 32 | 11 | 16 |
| 6 | 50 | 383 | 265 | 11 | 18 |
| 8 | 50 | 42 | 30 | 12 | 24 |
| 10 | 50 | 43 | 34 | 12 | 26 |
| 12 | 50 | 41 | 36 | 12 | 18 |
| 14 | 200 | 123 | 98 | 12 | 15 |

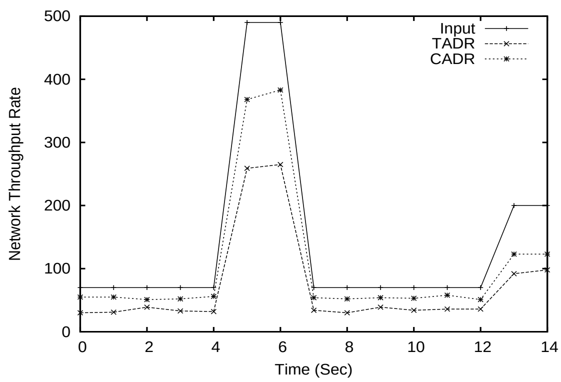


Figure 2: Network Throughput Rate

The End-to-End Delay is depicted in Fig. 3 and the comparison values are tabulated in Table 2. It is observed that the CADR exhibits highly reduced End-to-End delay for both normal (1 to 4s and 9 to 12s) and burstyy traffic (3 to 8s). Whereas, the TADR exhibits high End-to-End delay for both normal and bursty traffic (1 to 12s). Thus, there is tremendous decrease in End-to-End

Delay of about 76.5% in CADR 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.

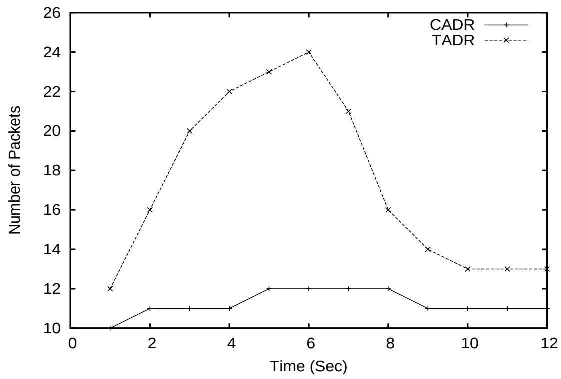


Figure 3: End-to-End Delay

## 7. Conclusions

The scarce resources in WSNs are highly vulnerable to congestion due to busty traffic caused by the different applications. Congestion mainly affects the network throughput thereby it degrades the overall network performance. Our proposed algorithm CADR considered most crucial parameters *viz* : minimum Queue Length, Depth, Distance and Maximum Residual Energy of each node while dispersing the traffic towards the sink. The network throughput has increased remarkably due to reduced congestion rate and fair queue length at each node in the network. The loop reduction has successfully implemented by considering the Distance as one of the key parameters results in minimized End-to-End delay and energy utilization. The CADR Shows better Network throughput and also satisfy the fidelity requirement of different applications. Further, this work can be extended to support better packet delivery rate for high load conditions and fidelity requirements of strict delay sensitive applications.

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