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Congestion detection technique for multipath routing and load balancing in WSN

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Abstract In WSN, nodes collect the information from the surrounding environment and transferring to base station. Multiple data transmission in a WSN causes the nodes near the base station to get congested. Here we propose to develop a congestion avoidance and mitigation technique. For that, we select routes based on the distance between sender and receiver, relative success rate (RSR) value of node and buffer occupancy of a node. Based on these three parameters, we define a utility function to be applied to each neighbor of a transmitter node. Hence the transmitter node chooses the highest U-valued node as its next hop node among its neighbors in packet forwarding. Thus we avoid congestion by choosing non-congested nodes as its next hop node and then we mitigate congestion based on RSR values.

Keywords WSN · RSR · Transmitter node · Packet forwarding

1 Introduction

Wireless sensor network (WSN) is composed of a large number of cooperative sensor nodes, which are densely deployed either inside the phenomenon or very close to it. Depending on the application, the number of nodes may reach an extreme value of millions. A sensor node is made up of four basic components namely sensing unit, processing unit, transceiver unit and power unit [1, 2–5]. Sensor nodes should be cheap, battery-powered, easy to install, capable of self-organization, and usually deployed densely in hostile environments [6, 7–9]. There are various types of sensors such as radar, thermal, visual and infrared, which can sense the environmental conditions such as temperature, pressure, sound and humidity [10]. However, sensor introduces several resource limitations due to the lack of memory, power, computational resources, and reliability [10, 3, 11–14].

Congestion restraint generally follows two steps: congestion detection and congestion control. Congestion detection is the methodology in which that abnormality in the normal traffic is been made out i.e. when a packet is been transferred from one node to other predicament events can happen [15, 16–19].

Congestion control techniques are based on detection of congestion and recovery, but they cannot eliminate or prevent the occurrence of congestion. Collision is a symptom of congestion in the wireless channel and can result in a time variant channel capacity [20, 12, 21–24].

There are several factors that cause congestion. When packet arrival rate exceeds the outgoing link capacity, when the receiving nodes buffer is not sufficient to store the incoming data packets, when traffic arrives in bursts, when the incoming rate is greater than the service rate, the network will start dropping the packets [25, 17, 26–28].

Also the variable transfer rates might cause network congestion due to concentrated packets in case of a concurrent occurrence of multiple events [29, 30–33].

In order to reduce congestion, the routing protocol should reduce the number of packets in the network; however, simply dropping overflowed packets will reduce the data fidelity and increase the energy dissipation. Conventional congestion control protocols usually use a backpressure scheme, which reduces congestion by reducing the

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transfer rate of child nodes of a congested node and by decreasing the packet generation rate of a sensor node that causes heavy traffic [29, 34].

During congestion, sensor nodes usually drop the overflowed packets; however, packet drops lead to data loss and unnecessary energy dissipation. But reliable data delivery is inherently correlated to congestion [29]. There are many sources for congestion such as, buffer overflow, concurrent transmission, packet collision and many to one nature [15, 35].

1.1 Problem identification

Congestion avoidance and mitigation (CAM) protocol [36] is used to avoid and mitigate congestion by utilizing accuracy by data-rate adjustment. The congestion level of each node is described based on the relative success rate (RSR). However, if RSR value of a node is 1, the proposed did not discuss how to improve data generation rate using small factor of the work i.e., 10 % of current rate. When the data generation rate is increased the congestion status of all nodes was declined which causes higher number of packet drops and eventually reduces the average success rate of critical data at the BS.

For congestion avoidance utility function of (3) in [36] is applied to each neighbor of transmitter node. When transmitter node forwards a packet it chooses the highest utility function among its neighbor. This function is selected based on two components such as distance of next node as well as RSR parameters.

From this Eq. (3) we have included another parameter of buffer occupancy ratio from [37]. It is the combination of incoming and outgoing traffic of each node. The neighbor node buffer the incoming and outgoing traffic by the transmission capacity and number of active connection across the main node.

In order to overcome these issues, we proposed a congestion detection technique for multipath routing and load balancing in WSN.

The paper is organized as follows. Section 2 describes the related works and Sect. 3 provides the detailed explanation of the proposed work. Section 4 explains the simulation results. Finally, Sect. 5 concludes the work.

2 Related works

See Table 1.

3 Proposed contribution

3.1 Overview

Data transmission in WSN comprises of nodes collecting all the information and transferring to base station. Multiple data transmission in a WSN causes congestion of nodes near the base station as all the routes leads to base station. Here we propose to develop a CAM technique. For that, we select routes based on the distance between sender and receiver, RSR value of node and buffer occupancy of a node. Based on these three parameters, we define a utility function to be applied to each neighbor of a transmitter node. Hence the transmitter node chooses the highest U-valued node as its next hop node among its neighbors in packet forwarding. Thus we avoid congestion by choosing non-congested nodes as its next hop node and then we mitigate congestion based on RSR values (Fig. 1).

3.2 Congestion control

Congestion can be prevented by choosing non-congested routes in routing phase. Once congestion occurs, it can be mitigated by utilizing an accurate data-rate adjustment. The route selection is done based on the distance between each pair of sender and receiver which leads to high end to end success rate of data transmission.

3.2.1 *Congestion level*

Let us consider a contention based MAC protocol. The packet sending rate of the nodes in congested area reduces due to heavy competition among them to access the medium [36]. The active congestion level (CL) of that node for a small period can be better measured as follows:

$$CL = 1 - RSR \tag{1}$$

where RSR is the relative success rate given by

$$RSR = \frac{NoPTx}{NoPFx} \tag{2}$$

where NoPTx and NoPFx are the number of packets transmitted at the MAC layer and number of packets forwarded at the network layer, respectively, for a given period of interval.

RSR value is determined at network layer. After every fixed interval, MAC layer sends a feedback to the network layer regarding the number of successful transmissions for that interval. The nodes periodically broadcast the RSR values. Each node utilizes these RSR values of each neighbor to choose the next node towards the base station. In addition, distances of neighboring nodes are also considered during route selection process as the distance factor ensures high end to end packet success rate.

3.2.2 *Buffer occupancy ratio*

The change in buffer occupancy can be modeled regarding incoming and outgoing traffic as [37]

Table 1 Comparison of existing works

Techniques	Advantages	Disadvantages
Fuzzy technique to control congestion [10]	Use local information such as packet loss rate and delay to control congestion in the network. Performance is high by satisfying QoS requirements. Improve network lifetime	Even if the congestion is reduced, this mechanism considerably increased the overhead while performing congestion control operation
Adaptive compression-based congestion control technique [29]	Congestion control can be effectively performed along with packet reduction in case of congestion	At the reduction of overflowed packets and set the nodes to the sleep state for some time, the network efficiency is decreased due to overflowed packets in the congested nodes
Congestion avoidance and mitigation (CAM) protocol [36]	Improved the reliability and the timeliness of data transmitted by the critical nodes (i.e., nodes close to the current event) through congestion avoidance and mitigation	The increase in regular data generation rate, the congestion status of all nodes deteriorates which causes higher number of packet drops and eventually reduces the average success rate of critical data at the base station
Congestion and delay aware routing (CODAR) protocol [39]	Mitigate congestion using an accurate data-rate adjustment. CODAR emphases the successful collection of these control information which eventually provides desirable performance	During the operation of CODAR the uniform node density is not desirable
Active congestion detection mechanism based on network tomography [25]	Path-level congestion detection can be effectively performed using loss rate and delay, whereas link-level congestion detection technique is based on network tomography	Not suitable for large-scale network congestion control mechanism
Learning automation based congestion avoidance algorithm [40]	Depending on the traffic load at each node the optimal rate of flow of data was maintained. Also, counter the congestion problem in WSNs effectively	It did not describe how this approach needs to be changed for non-stationary environments
Innovative model and congestion control algorithm [37]	Utilizes Feedback Congestion Control (FBCC) and linear discrete time control theory. FBCC detects the onset of congestion using queue length	It did not address the buffer overflow because of the imbalance between incoming and outgoing flows due to congestion

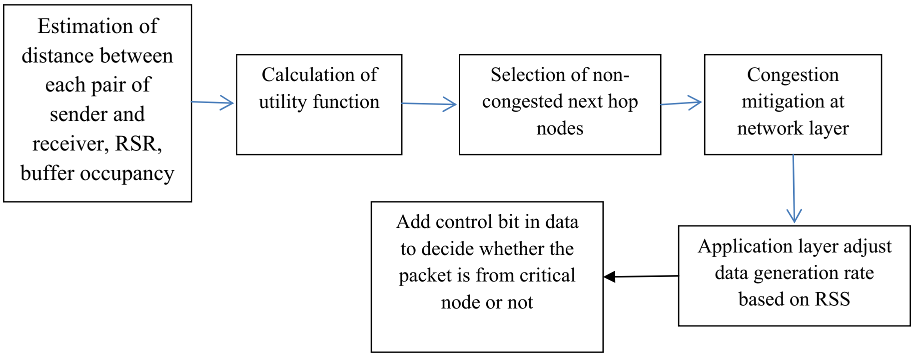

Fig. 1 Block diagram of the entire scheme

$$b_i(t+1) = St_{b0}(b_i(t) + Ic_i(t) - g_i(t)) \tag{3}$$

where $b_i(t)$ is the buffer occupancy of a node at time instant T. St_{b0} is the saturation function representing the finite-size queue behavior. I is the measurement interval. $c_i(t)$ is a regulated (incoming traffic) which should be calculated and propagated as a feedback to the node i − 1 located on path to source, which is used to estimate the outgoing traffic for this upstream node $g_i(t)$. $g_i(t)$ is an outgoing traffic dictated by next hop node i + 1 and distributed by channel state changes.

The behavior of Feedback Congestion Control Protocol is modeled using Stochastic Differential Equations. Consider a queue system with father node and his four children. The father node has a transmission capacity of TC and A number of active connections crossing the link i. The children node has a outgoing traffic denoted by $g_1(k)$, $g_2(k)$, $g_3(k)$, $g_4(k)$ respectively. Then the buffer dynamics is estimated as

$$dg_i = (c_i - g_i)g_i \frac{\sum g_i - \frac{b_o - b(k)}{I} - TC}{\sum g_i} dt \tag{4}$$

The above equation can be linearized at operating point (c_0, g_0, b_d) so that we get

$$M = \left(\sum g_i\right)^{-2}(c_i - 2g_i)\left(\sum g_i - \frac{b_o - b_d}{I} - TC\right) + (c_i - g_i)g_i\left(4 - \frac{b_o - b_d}{I} - TC\right) \tag{5}$$

$$A = g_0 \frac{\sum g_0 - \frac{b_o - b_d}{I} - TC}{\sum g_i}; b_d = \frac{TC}{A_0} \tag{6}$$

The saturation function prevents $b_i(t)$ form being negative or growing infinitely in case of no-congested paths. TC be the link capacity in packets/s and A is the number of active connections crossing the link i. The nonlinear model can be expressed in form of following linear model.

$$\dot{z}(k) = Mz(k) + Ac(k) \tag{7}$$

Then this equation is approximately discreted

$$g_i(t+1) = (M+1)g_i(t) + Ac_i(t) \tag{8}$$

Let

$$\mathrm{X(t+1)} = (b_i(t+1), b_i(t), g_i(t+1), g_i(t))^I \tag{9}$$

From Eq. (9) and (10), we obtain the dynamic equation

$$\mathrm{X(t+1)} = EX(t) + FC(T) \tag{10}$$

The linear discrete model as per Eq. (11) enables the design controllers to achieve asymptotic stability of desired operating point and fairness congestion algorithms in

3.2.3 Congestion detection

Here we describe congestion avoidance as well as energy dissipation issue. Energy dissipation is a primary factor in WSN. If route selection is based on distance of nodes, then there may be repeated usage of same routes in a static network. This will leads to few particular nodes closer to BS to die out of energy soon. When routes are chosen randomly, there will be uniform energy dissipation but reduced data success rate.

The RSR values of nodes vary time to time based on the current active congestion conditions of nodes. Hence routes will be random for routes chosen based on distances as well as RSR parameters of neighbors. With distance of neighbors a selection criterion, data success rate will be sufficiently high.

Now, we introduce a utility function U to be applied to each neighbor of a transmitter node B. Therefore, while packet forwarding, B chooses the highest U-valued node among its neighbours. The function U consists of two components

(1) Distance of next node to ensure high packet success rate
(2) Relative success rate (RSR) of each neighbor so as to avoid congested nodes
(3) Buffer occupancy of a node at time to provide feedback based congestion control

Therefore by combining the three, we estimate utility function as

$$\mathrm{U(t)} = p \times \frac{L_t}{L} + q \times RSR_t + r \times b_i(T) \tag{11}$$

where L_t is the distance of next node t towards the BS from node B, L is the maximum distance covered by transmission power of each node, RSR_t is the relative success rate of node t, $b_i(T)$ is the buffer occupancy of node at time T

$$p + q + r = 1 \tag{12}$$

RSR prevent congested nodes thereby reducing congestion formation which helps lowering packet delay. The Buffer occupancy is used to detect the onset of congestion using queue length via feedback congestion control scheme.

Algorithm for congestion avoidance

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procedure CAM_AVOIDANCE (Neighbor list NL, Distance list LL, Success list RSRL, Buffer list BL)
variables: node R, node k, real U
for each node k in NL
$U = p \times \frac{LL(k)}{L} + q \times RSRL(k) + r \times BL_i$
Let, node R has the highest value of U among all nodes in NL
Return R
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Let each node aware of its location. Hence each node k broadcasts its location, RSR value using control packets after receiving a fixed number of packets from other nodes or after a fixed interval whatever is earlier. Then buffer occupancy is determined after every updates. Then utility function is estimated.

3.3 Congestion mitigation

The network layer mitigates its own congestion after calculating RSR. The network layer then sends the RSR value to application layer.

(1) If RSR value <1, the application layer decreases its data generation rate to RSR factor of the current rate.
(2) If RSR value = 1 (the maximum possible value) and the application layer has a lesser data generation rate than its targeted rate, then it increases its data generation rate by a small factor (10 % of current

rate) and waits for the next value of RSR arriving from the network layer.

(3) Similarly, the application layer always retains its targeted data generation rate without congestion.

(4) If the packets come from other nodes, the network layer simply relays RSR factor of the packets to MAC layer and drops the remaining packets.

(5) While dropping packets coming from other nodes, the network layer tries to forward as many critical packets (packets sent by nodes close to the event) as possible for the BS to attain maximum number of critical packets so that the event can be detected reliably and timely.

Each data packet consists of a control bit which is set to 1 if the packet is generated by a node close to the event; otherwise, it is set to 0. This bit can be examined by a node to decide whether a packet received from other node is critical or not. It may be noted that CAM utilizes an accurate rate adjustment in accordance to node's active CL.

3.4 Overall algorithm

(1) Congestion in WSN can be prevented by proper selection of non-congested nodes in the route selection phase.

(2) The next hop node is chosen based on utility function which depends on distance between sender and receiver pair, RSR of each neighbor, buffer occupancy ratio.

(3) The distance between each sender-receiver pair is considered for route selection which ensure high packet success rate.

(4) The RSR values of nodes vary time to time based on the current active congestion conditions of nodes. It is determined at network layer.

(5) Buffer occupancy of a node at time to provide feedback based congestion control.

(6) With these parameters utility function is estimated.

(7) The node with highest utility function is chosen as next hop node for data forwarding by the transmitter node.

(8) Then congestion mitigation is done based on RSR value. Based on RSR value, data generation rate is varied.

(9) The network layer forwards the RSR factor of the packets coming from other nodes and drops the remaining ones.

(10) The network layer tries to forward as many critical packets while dropping packets from other nodes. So the BS can obtain maximum critical packets to detect the event reliably and timely.

(11) The control bit of data packet determines whether the packet is critical or not.

(12) Thus congestion is mitigated reliably.

4 Simulation results

4.1 Simulation model and parameters

We used NS-2 [38] version 2.32 to simulate the proposed Congestion Detection Technique for Multipath Routing and Load Balancing (CDTMRLB) based routing protocol. The number of nodes is 100 for 50 s simulation time. During the simulation, the data sending rate is varied from 100 to 500 Kb. The simulated traffic is constant bit rate (CBR). The simulation settings and parameters are summarized in Table 2.

The performance of CDRMRLB is compared with the CAM [36] and feedback based congestion control (CBCC) [37] protocols. We evaluate mainly the performance according to the following metrics.

Average packet delivery ratio It is the ratio of the number of packets received successfully and the total number of packets transmitted.

Delay It is the time taken by the packet to reach the receiver.

Energy It is the average energy consumed for the data transmission.

Throughput It is the total number of packets received by the receiver.

4.2 Results

The data sending rate is varied as 100,200,300,400 and 500 Kb and the performance of the three protocols are evaluated in terms of the above metrics.

Figures 2, 3, 4 and 5 show the results of delay, delivery ratio, packet drop and throughput for the CDTMRLB, CBCC and CAM protocols by varying the rate. When

Table 2 Simulation parameters

No. of nodes	100
Area Size	750 × 750 m
Mac	802.11
Routing protocol	CDTMRLB
Simulation time	50 s
Traffic source	CBR
Packet size	512 bytes
Initial energy	8.5 J
Antenna	OmniAntenna
Rate	100, 200, 300, 400 and 500 Kb

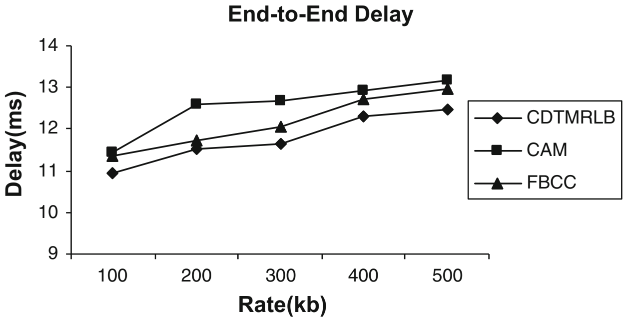

Fig. 2 Rate versus delay

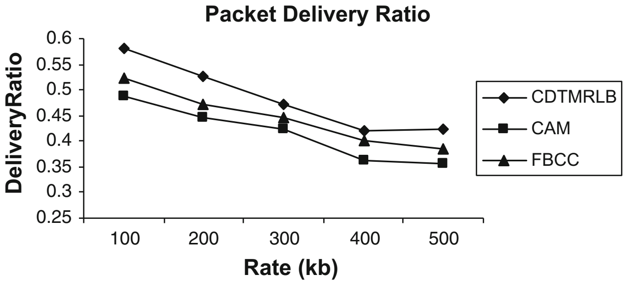

Fig. 3 Rate versus delivery ratio

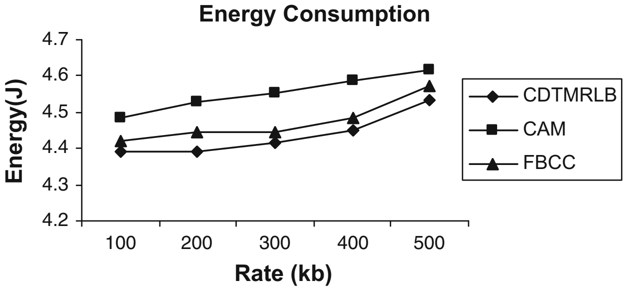

Fig. 4 Rate versus energy

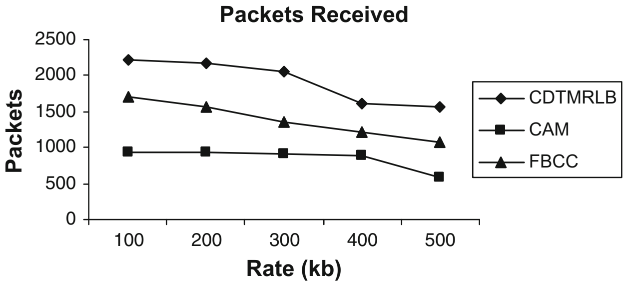

Fig. 5 Rate versus throughput

comparing the performance of all the three protocols, CDTMRLB achieves the best performance in terms of the all the metrics, followed by FBCC and CAM. As we can see from the figures that, CDTMRLB outperforms CAM by 7 % in terms of delay, 14 % in terms of delivery ratio, 2 % in terms of energy consumption and 55 % in terms of throughput. Similarly, CDTMRLB outperforms FBCC by 3 % in terms of delay, 8 % in terms of delivery ratio, 1 % in terms of energy consumption and 28 % in terms of throughput.

5 Conclusion

In this paper, congestion detection technique for multipath routing and load balancing is proposed for WSN. In this protocol, congestion is avoided by selecting the non-congested nodes as next hop nodes in the routing. The next hop nodes are chosen based on the parameters distance, relative success rate (RSR), buffer occupancy. The data generation rate is adjusted based on the estimated RSR value. Simulation results show that the proposed protocol reduces the packet drop and energy consumption and improves packet delivery ratio.

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