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Study of Traditional Upstream Congestion Control Algorithm with various Metrics in Realistic WSN Scenarios

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Abstract

Wireless Sensor Networks (WSNs) utilize huge amount of wireless sensor nodes to gather information from their sensing terrain. The gathered information will undergo in-network process and send to the remote sink. In this densely distributed network high packet flow occur near the sink due to the convergent nature of upstream traffic. Congestion may occur in the network and cause packet loss. Due to this packet loss the throughput may be lowered and also, congestion leads to excessive energy consumption. Therefore congestion has to be controlled to prolong the sensor nodes lifetime. In this paper a study of traditional fairness congestion control algorithm named Congestion Control and Fairness (CCF) algorithm in realistic different scenarios is done. The traditional algorithm is implemented in NS 2, and analyzed the performance of latency and protocol overhead. Results show that the latency is increased when the number of nodes is increased from 60 to 80 and 100. Also, the protocol overhead increases linearly when the simulation time steps in for all the scenarios.

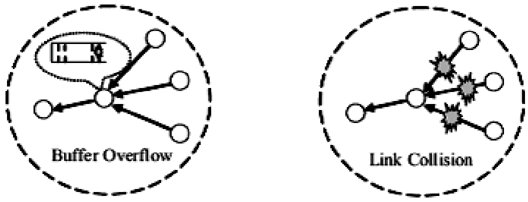
Index – congestion control, fairness, latency, protocol overhead, sensor nodes, wireless sensor networks.

1. Introduction

WSN consists of large amounts of wireless sensor nodes, which are compact, light-weighted, and battery-powered devices that can be used in virtually any environment. With this data simple computations are carried out and communicate with other sensor nodes or controlling authorities in the network [22]. Wireless communication is a major source of energy consumption in WSNs. WSN have lately attracted in plenty of applications which include environment monitoring such as temperature, sound, pressure, vibration, pollutants, etc. at different locations, mobile object tracking, and navigation applications. All these applications consist of many inexpensive wireless sensor nodes that are capable of collecting, processing and storing various information. These applications are normally implemented in an ad hoc manner to operate in a distributed way. In wireless sensor applications all sensor nodes periodically report data to a single sink node which realizes a many-to-one communication model [3]. The congestion traffic is found in two streams, named downstream traffic and upstream traffic. The downstream traffic from the sink to the wireless sensor nodes is a one-to-many communication model. The upstream traffic from sensor nodes to the sink is a many-to-one communication model.

The convergent nature of the upstream traffic in the upstream direction probably appears as congestion and the upstream traffic will create high bit rate with the development of diverse application in the WSNs. Thus congestion leads to packet losses and increased transmission latency and has direct impact on the energy-efficiency and congestion must be efficiently controlled. Every packet transmitted in the WSNs contains useful information, which can be utilized through packet-based computation and to enhance congestion control. The WSN packet computation has small packet forwarding rate and the forwarding computation capability is limited.

Most of the time the sensor nodes are modeled with limited energy, as a result the sensor nodes lacks recharging issues. But still wireless nodes packet-based computation is preferred since it is generally known that the computation utilizes reduced energy than the communication [1]. There are two types of congestion that could occur in WSNs and is shown in figure 1 [19]. The first type is node-level congestion that is common in conventional networks. It is caused by buffer overflow in the node and can result in packet loss and increased queuing delay. Packet loss in turn can lead to retransmission and therefore consumes additional energy. For WSNs where wireless channels are shared by several nodes using Carrier Sense Multiple Access (CSMA) protocol, collisions could occur when multiple active sensor nodes try to seize the channel at the same time. This can be referred to as link-level congestion. Link-level congestion increases packet service time, and decreases both link utilization and overall throughput, and wastes energy at the sensor nodes. Both node level and link-level congestions have direct impact on energy efficiency and Quality of Service (QoS).



(a) node-level congestion (b) link-level congestion

Figure 1Congestion in WSNs

To attain the QoS requirements, the network resources should be used in a fair and efficient manner. Moreover, techniques such as data compression, data fusion and aggregation become very useful in maintaining robustness. Due to the changes in node mobility and wireless channel failure, the wireless sensor network seems to be unreliable in nature. In order to efficiently use the wireless sensor network for real-time applications the issues related to the wireless protocols are reduced.

The rest of the paper is organized as follows. Section 2 reviews about the related literature and section 3 describes the detailed design of the traditional fairness congestion control protocol in WSNs. Section 4 details the experimental setup of the traditional fairness congestion control protocol using NS 2, and performance analysis for the metric latency and protocol overhead, and finally conclusion and future scope is given in section 5.

2. Related Work

In this section, we review the prior work on improving the congestion control over WSNs. Sichitiu [15] proposed a cross-layer TDMA-based protocol that guarantees collision-free communication by scheduling slots for each node and results in significant energy savings. This has the main challenge to determine the collision-free slots that are to be assigned to wireless nodes in a multiple-hop network.

Davy et al [5] presented policy-based architecture to enable autonomic communications. To implement autonomic algorithms and protocols that manages the network. Thus, the autonomic plane should be divided into two blocks. The knowledge sub-plane performs the first task, while the control sub-plane performs the latter, using policies to configure the behavior of the algorithms.

Baldauf et al [2] presented a survey on context-aware systems. The network makes requests based on addresses, service and data mobility is a big issue. Whenever a service is inserted, deleted or moved, a lengthy notification process must be undertaken. All nodes on the network that are using this service or that cached its location must be informed of its new position. Another problem with content being bound to an address is a Content Delivery Network (CDN) mirroring that requires a non-trivial set of mechanisms, such as Domain Name System (DNS) redirects and explicit content rewriting.

Mande et al [10] proposed a multipath routing algorithm for wireless multimedia sensor networks. In this, a set of node-disjoint routing paths is found by a mazing search algorithm to reduce the number of energy consumption gathering nodes and high risk nodes of network congestion. The multipath selection employs a type of congestion control message, a gradual increase strategy based on a path and a gradual increase strategy based on a flow to balance load and energy.

Mohammad et al [11] presented a new Queue based Congestion Control Protocol with priority support, using the queue length as an indication of congestion degree. In this approach, the rate assignment to each traffic source is based on its priority index as well as its current congestion degree. Chonggang et al [4] proposed a node priority-based congestion control protocol for WSNs. In this, the node priority index is introduced to reflect the importance of each node and uses packet inter-arrival time along with packet service time to measure a parameter defined as congestion degree and imposes hop-by-hop control based measurement as well as node priority index.

Ibrahim et al [7] addressed non-trival performance problems in contention-based wireless networks and presented a method for admission control in contention-based networks, implemented as a component of a performance management system. The system can be used as a tool for dimensioning and configuration as well as for real-time admission control. The often unpredictable dynamics in contention-based access networks means that continuous performance control is needed to maintain a desired QoS.

Ni et al [12] proposed a data fusion strategy for WSNs based on trust and cluster. In the intra-cluster, data fusion is done by setting up the relay node and using the trust value of the node as weight of data. The selection principle of relay node, and the data fusion are based on the trust. The effective and energy consumption of the data fusion algorithm are analyzed and illustrated through an example.

Liqiang et al [9] proposed an energy efficient congestion control scheme for sensor networks called Enhanced Congestion Detection and Avoidance which comprises of three mechanisms. First, the approach uses buffer and weighted buffer difference for congestion detection. Secondly, proposed a bottleneck-node-based source data sending rate control scheme and finally uses a flexible queue scheduler for packets transfer. Wang et al [20] proposed a novel network cognition and congestion control model based on Neuroendocrine-immune system that introduced natural inspired computation concept and is designed to improve the overall transmission performance of heterogeneous network.

Lazarou et al [8] proposed a cluster head method to allow parallel transmission of data packets to form a schedule by arranging data transfer at each round. The cluster head accepts request for data transfer and assigns a slot for each node wishing to transmit. Each node of data transfer is divided into contention, data transmission and idle period. In WSN the single point of failure is eliminated by providing a decentralized control and nodes that have no data to send waste time slots in the contention period where idle listening and overhearing occurs.

Seshadri et al [13] proposed a router-assisted congestion control protocol called QFCP. The QFCP can significantly shorten the flow completion time, fairly allocate bandwidth resource, and is robust to non-congestion related losses. Also an extensive study on QoS for real time multimedia application is made and result depicts an improved QoS for specified TCP based scenarios. Shuqiang et al [14] presented a routing protocol called cross-layer AODV, based on a cross-layer design and ad hoc on-demand distance vector routing protocol. The proposed protocol adopts two mechanisms called delaying transmission and efficient broadcasting to address the broadcast storm problems in WSNs such as high probability of collisions and redundancy of broadcasting.

Tongying et al [17] proposed that information fusion is an effective way to reduce the communication data, and to save the energy consumption and thereby extend the life of the network. This is done with the specific analysis of an information fusion algorithm based on rough set. Young et al [21] suggested an adaptive rate control for congestion avoidance in WBANs. The scheme performs rate control dynamically each node based on a predication model which uses rate function including congestion risk degree and valuation function, without requiring congestion detection and congestion notification steps.

Vasos et al [18] examined the performance of SenTCP, Directed Diffusion and HTAP, with respect to their ability to maintain low delays, to support the required data rates and to minimize packet losses under different topologies. The topologies used as simple diffusion, constant placement, R-random placement and grid placement. It is shown that congestion control performance in sensor networks are significantly improved to forward the data in case of congestion.

3. Traditional Fairness Congestion Control Algorithm

CCF is a distributed and scalable algorithm that eliminates the congestion within a sensor network and ensures the fair delivery of packets to a sink node [6]. CCF is designed to work with any MAC protocol in the data-link layer. CCF uses packet service time to deduce the available service rate. Congestion information is implicitly reported. It controls congestion in a hop-by-hop manner and each node uses exact rate adjustment based on its available service rate and child node number. CCF guarantees simple fairness. CCF has two problems [19].

The rate adjustment in CCF relies only on packet service time which could lead to low utilization when some sensor nodes do not have enough traffic or there is a significant packet error rate. Moreover, it cannot effectively allocate the remaining capacity and as it uses work conservation scheduling algorithm, it has a low throughput in the case that some nodes do not have any packet to send. CCF is used as a distributed and scalable algorithm to eliminate congestion within a sensor network and ensures the fair delivery of packets to the sink node. CCF guarantees simple fairness and has two major problems [4].

Consider a set of N wireless sensor nodes and each wireless sensor node has an infinite amount of data to be sent to a single destination. The nodes will create data traffic and route traffic through the other nodes. That is all the node can act both as a source and a router. The wireless sensor nodes sense the information periodically and encode the information into data packets.

The encoded information in the form of data packets are then sends to the destination or sinks [16]. Let f_i be the flow originating from the node i and r_i be the rate at which the flow f_i is generated into the sensor network. It is assigned that the data flow is fair enough and the data rate is efficient. The rate does not include the rate at which node i forwards the traffic. When there is a collision on the link near the node i, then the node i and its neighboring nodes should reduce the channel utilization in order to prevent further link-level congestion. The protocol will improve the channel quality by including a phase-shifting effect among neighboring nodes.

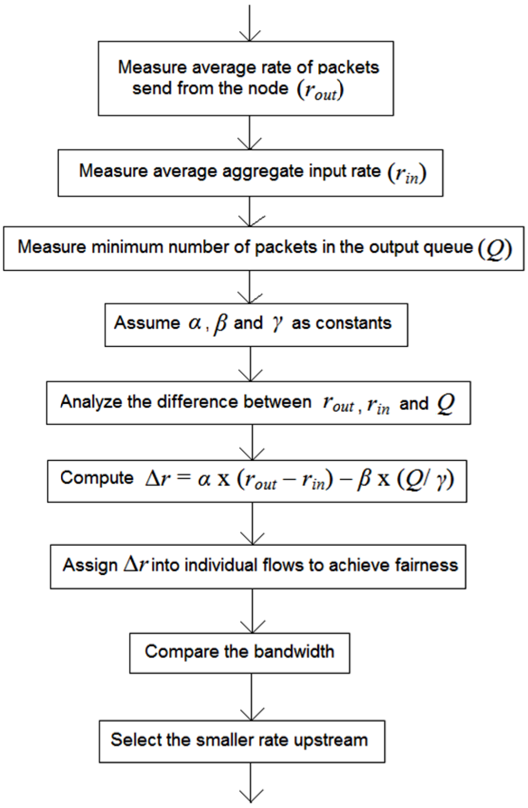


Figure 2 Flowchart for CCF Algorithm

Figure 2 depicts the flowchart executed at each node for the congestion control. The control interval is the time period over which a node takes a control decision regarding the increase or decrease in the transmission rates of the flows originated by the node itself and the flows being routed through the node. The interval is considered to be the average feedback delay of the flows passing through the gateway node. The congestion control algorithm is invoked every control interval at the gateway nodes. A node is called a gateway node if it is one hop away from the sink.

Congestion Control Algorithm

The CCF congestion control algorithm has the following steps to be executed at each node in every control interval [16].

Step 1

Measure the average rate (r_{out}) at which the packets are sent from the node, the average aggregate input rate (r_{in}), and the minimum number of packets in the output queue which is seen by an arriving packet in a control interval (Q).

Step 2

Based on the difference between r_{out} and r_{in}, and Q, compute Δr. This is the total change in aggregate traffic.

$$\Delta r = \alpha \text{ x } (r_{out} - r_{in}) - \beta \text{ x } (Q/\gamma)$$

Step 3

Assign Δr into individual flows to achieve fairness

Step 4

Compare the bandwidth computed for each flow with the bandwidths. Use and propagate the smaller rate upstream.

Algorithm Requirements

The following are the congestion control algorithm requirements [16].

i. Estimation of average aggregate output rate
ii. Estimation of average aggregate input rate
iii. Computation of the total change in aggregate traffic required to control efficiency
iv. Assign the total change in aggregate traffic into individual flows to obtain desired fairness
v. Propagation of rate upstream
vi. Estimation of the control interval

4. Simulation Results

The simulations are carried out with three different scenarios using wireless sensor nodes communicating via IEEE 802.11 MAC layer protocol model with a transmission range of 200 meters. The simulation environment is implemented in the NS-2, a network simulator that provides support for simulating wireless networks. NS-2 is written using C++ language and uses the Object Oriented Tool Command Language (OTCL). It is an extension of the Tool Command Language (TCL). The simulations are carried out using a sensor environment roaming over a simulation area of 1500 meters x 1500 meters flat space operating for 600 seconds of simulation time. The network topology used in the simulation is a simple single-path routing model. Nodes in this simulation move according to the Random Way Point Mobility model [21], which is in random direction with speed ranges that vary from 0 m/s to 20 m/s and the buffer size is set to 100 packets. The mobility of different levels is obtained by changing the maximum node speed with a pause time of one second. The sensing node in WSN is usually stationary or moves with a walking speed of about 1 m/s. We evaluate the performance of the CCF protocol [6] on a wireless network environment in the following three different scenarios.

Scenario 1 - A wireless environment consisting of 60 wireless sensor nodes.
Scenario 2 - A wireless environment consisting of 80 wireless sensor nodes.
Scenario 3 - A wireless environment consisting of 100 wireless sensor nodes.

Performance has been analyzed for the metrics latency and protocol overhead, and is described below.

Latency

Network latency is a measure of how fast a network is running. It refers to the time between the transmissions of data packets from a source and the time of its reception by a receiver. Latency is the delay between the initiation of a network transmission by a sender and the receipt of that transmission by a receiver. In a two way communication, it may be measured as the time from the transmission of a request for a message, to the time when the message is successfully received.

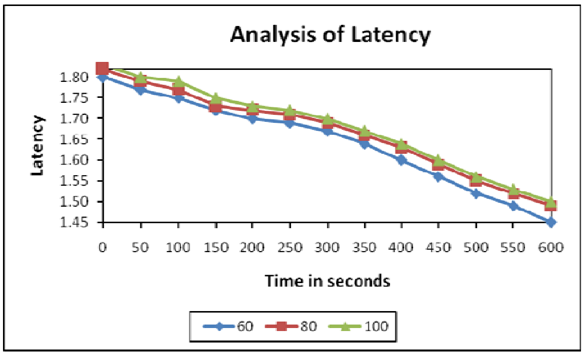


Figure 3 Analysis of Latency

Figure 3 shows the analysis of latency of traditional CCF algorithm under all the three different scenarios with wireless network environment. The average latency for the scenario 3 has the highest compared to that for the other two scenarios. But the latency lowers when there is an increase in pause time, which is almost common in all the simulation scenarios. Initially, the latency for all the simulation scenarios is more or less constant, and later linearly decreased to about 4 to 5 % in the delay till the end of the simulation, since a stabilized path is established in the middle of the simulation period. Generally, the performance when the nodes move with lower speed is better than that when moves with higher speed. The reason is that the mobility may lead to more link breakage and hence will increase the rate of retransmission of packets. A system with reduced latency will increase the energy-efficiency of the wireless sensor nodes and will definitely extend the system lifetime. Comparing the three scenarios for the traditional CCF algorithm has an average latency of about 1.66 milliseconds.

Protocol Overhead

Protocol packet overhead is the ratio of the number of protocol packets originated or forwarded, related to the route creation process that are received by a node per data delivery. This metric indicates the percentage of the total protocol messages transmitted for data forwarding. Figure 4 shows the analysis of protocol overhead of traditional CCF algorithm under all the three different scenarios with wireless network environment. During the simulation, it is seen that most of the time all the graphs are in overlapped form and all the simulation scenario graphs are linearly raised during the simulation. The CCF algorithm has an average protocol overhead of 3 MB. In the simulation environment, as the number of wireless sensor nodes increases, the control message transmitted is minimized, by means of reducing the number of forwarding nodes.

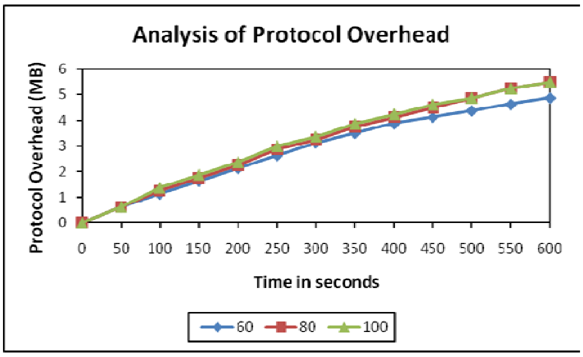


Figure 4 Analysis of Protocol Overhead

5. Conclusion

In this paper, the traditional fairness congestion control protocol is implemented in NS 2 with different scenarios. This is a distributed algorithm that seeks to assign fairness and rate efficiently to each node. This algorithm very aggregately monitors each nodal input and output traffic rate. The algorithm varies the transmission rate of the node and its upstream nodes. This introduces node priority index and is simulated for a single-path routing environment. The simulation result shows that the fairness algorithm provides remarkable throughput, and is able to attain fairness for all the sensor nodes in the network and acquire the transmission rate quickly. This work can be extended for multi-path routing environment too. An agent based approach can be used with the fairness congestion control algorithm to further reduce packet loss and which in turn improves energy-efficiency, and provides lower delay. This work can also be extended to integrate data aggregation schemes to reduce further energy consumption and to increase the battery life-time of the sensor node.

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