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Congestion Control Techniques in Wireless Sensor Networks – A Survey

Dr. Sandhya Rachamalla
Associate Professor
Department of ECE
University College of Engineering
Osmania University, India

Abstract: Congestion control is a challenging task in Wireless Sensor Networks (WSNs) as it upset Packet delivery ratio (PDR), Latency, energy consumption, quality of output data retrieved at Base station (BS)/sink node. Node buffer overflow, link failure between nodes, channel contention, Interference, packet collision, high transmission rate at the source nodes are some of the reasons for Congestion in WSNs. With the development of WSN based on the Internet of Things (IoT), the importance of Congestion control increases and the need to provide more efficient strategies to deal with this problem is strongly felt. Optimization is always a challenging process in any network. This paper provides brief overview of the congestion control algorithms used in WSNs.

Keywords: Congestion Control, Wireless Sensor Networks, Centralized Congestion Control, Distributed Congestion Control

1. INTRODUCTION

Wireless Sensor Networks have gained the interest of the research community in the recent years due to the wide variety of applications that can be supported [5]. Smart sensor nodes are low power devices equipped with one or more sensors, a processor for computations, and memory for storage, a power supply, a radio transceiver to receive from other nodes and to transmit towards sink or base station (BS) and an actuator for mobility [6].

Congestion can occur in WSN while more than one source tends to transmit packets toward the only sink [7]. Traffic is high at the nodes near the destination and may result in packet loss due to buffer overflow or link failure, as shown in Figure 1

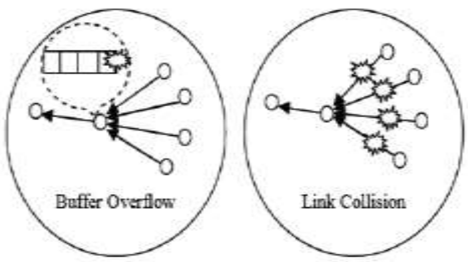

Figure 1 Buffer overflow at node and Link failure between nodes [7]

The buffer at the node can accommodate packets based on its size and drop the remaining packets resulting in packet loss and so as link failure between the nodes [2]. When the number of sources increases, network congestion increases resulting in decrease in probability of channel access thereby increasing the collision of packets at MAC layer. Due to the advancements in the wireless networks with IoT applications, the congestion control need to be addressed and cannot be neglected [3].

2. RELATED WORK

Many researchers have addressed the congestion problem in WSNs. In [1], the authors have provided well organized literature survey of Congestion control algorithms of WSNs with qualitative analysis of the existing schemes and their shortcomings. Rekha et al in [8] discussed the various congestion techniques with their pros and cons. They have classified the congestion techniques as node level and link level ones. In [4], the author discussed Congestion detection techniques, Congestion notification methods, Congestion control patterns and Cross-layer Congestion control mechanisms.

In [9], Congestion control protocols are discussed based on traffic controlled protocols and resource controlled protocols. Fusion's techniques mitigate congestion, queue occupancy detects congestion, hop-by-hop flow control improves the efficiency of the network. Centralized and Distributed congestion schemes are discussed in [10].

Congestion control schemes are categorized as Centralized and Distributed ones in [1]. In Centralized schemes, BS/sink will look after the Control process. In distributed category, the control algorithm is divided into various routines across the WSN. Several authors addressed the various Congestion issues in various types of application networks and came out with optimal solutions to control Congestion. The following sections describe the various Congestion control algorithms.

3. CONGESTION CONTROL ALGORITHMS

Congestion control algorithms for WSNs can be classified as Centralized and distributed ones.

3.1 Centralized Congestion algorithms for WSNs

The Congestion control task in the network if is taken care by the Sink/BS, they are categorized as Centralized Congestion algorithms. The following are some of the algorithms whose activities are carried at Sink/BS level.

1. Directed Diffusion: This protocol [11] uses data diffusion using interest gradients. Each sensor node names its data with one or more attributes, and the other nodes express their interest depending on these attributes. Interest is a set of data descriptors for the data for which the querying node is interested. Data is hence propagated along the reverse path of the interest propagation. Each path is associated with a gradient that is formed at the time of interest propagation. While positive gradients encourage the data flow along the path, negative gradients inhibit the distribution of data along a particular path.

2. ESRT: Event-to-Sink reliable Transport protocol [12] is Congestion control protocol which runs at the Sink. It takes into consideration the current reliability and congestion state of the network. Reliability levels are adaptively adjusted to the required one to conserve energy. Only sensed data from the event zone is collected by the sink.

3. PSFQ: Pump slowly, Fetch quickly is a reliable transport protocol which can be customizable to the user end applications. It claims minimum routing constraints and minimum signaling for data transmission ensuring reliability [13]. The idea is to distribute data slowly from source node and allow the nodes to fetch the lost data from neighbors quickly. The authors proposed hop-to-hop error recovery method where the intermediate nodes take care of lost data and recovery. Multi-hop forwarding operations are converted into series of single-hop transmission processes, thereby avoiding error accumulation.

4. RCRT: It is a rate-controlled reliable transport protocol suitable for loss-intolerant high- rate applications [14]. Sink controls the data-rates and takes care of congestion. Sink determines congestion levels and decides rate allocation. Based on its RCRT components, Sink determines whether network is congested and estimates the rate adaptation to be carried out in the path.

5. I2MR: Interference minimized multipath routing protocol with Congestion control [15]. It discovers multiple disjoint paths for load balancing. After the successful path discovery, source send the packets and if any intermediate node detects long term congestion, it sends a CONGEST packet to source. Upon receiving CONGEST packet, source invokes Congestion handle algorithm to reduce loading rate to next lower predefined rate. So, the source is made to send the data at the acceptable rate. If the source reaches the low loading rate and still receives CONGEST packet, then it switch to backup path. If the alternate paths are not available, then the source cannot send the data at specified rate.

6. TADR: Traffic-aware dynamic routing protocol is a Congestion control protocol in which the packets around the congested area are scattered along the multiple paths consisting of the under-loaded / idle nodes [16]. A virtual buffer of normalized queue length is used to steer the packets of congested area and to progress towards the Sink.

Table 1. Summary of the Centralized Congestion algorithms

	Congestion Scheme	Congestion Control Criteria
1	Directed Diffusion	Data aggregation with interest gradients
2	ESRT	Reliability levels are adaptively adjusted
3	PSFQ	Pump slowly from source and fetch quickly from neighbors
4	RCRT	Data rate control and allocation by the Sink
5	I2MR	Multiple disjoint path for load balancing
6	TADR	Traffic Diversion over under-loaded/idle nodes

3.2 Distributed Congestion Control Algorithms for WSNs

1. CODA: This paper proposes a distributed type of Congestion control scheme which that comprises of three mechanisms, receiver based congestion detection, open loop hop-by-hop back pressure and closed-loop multi-source regulation. In congestion detection, it uses the channel loading history to detect congestion at each receiver at low cost with sampling monitoring of local channel. If Congestion is detected, then back pressure messages are sent by the node towards the source as long as node detects congestion [17]. Source event rate is regularized in Closed-loop mechanism.

2. ECODA: Congestion detection and avoidance mechanism is proposed in this paper for different class of traffic. Measurement of congestion is done with weighted buffer and traffic differentiation is done with packet static and dynamic priority. Based on the priority the next packet is scheduled in flexible manner [18].

3. FCC [19]: This paper proposes a routing protocol with hybrid optimization. It consists of two steps. Firstly, next-hop node is selected with a multi-input time on task *optimization* algorithm offering minimal delay and then using *gravitational search algorithm* an efficient

route is to be selected from source to destination.

4. DAlPaS: Dynamic Alternative Path Selection approach for congestion control in WSN [20]. Initially source node transmits data over the available route in the network and if fault occurs, an alternate route is selected and routing table is updated. A binary tree based network is formed and hybrid epidermic algorithm is developed for it.

5. PCCP: Priority-based Congestion Control Protocol for WSN to control the congestion traffic. A priority table is created at each node and information is passed to all the other nodes. Congestion level is measured by the calculation of the ratio of packet inter-arrival time over packet service time. It is used to control the hop-by-hop upstream congestion with congestion degree level and packet table. PCCP optimizes the congestion control with packet-based computation work for single path /multi-path routes [21].

6. DPCC: Dynamic Predictive Congestion Control algorithm is a distributive type of Congestion control technique used in WSNs. In this algorithm Congestion is predicted at the node level, then traffic is broadcasted to the entire network dynamically. DPCC algorithm consists of three components.
   (i) Backward and forward nodes selection (BFS): According to the rate adjustment values, a node can select a forward node and other nodes which are not selected as forward node adjust the rates for their other backward nodes.
   (ii) Predictive Congestion Detection (PCD): Current congestion level at each node is measured using CI (Congestion Index) value and any nodes' CI value if less than 1 means the Congestion may occur.
   (iii) Dynamic Priority-based rate adjustment (DPRA): This component is used to adjust the traffic rates of backward nodes to avoid congestion [22].

7. LACAS: Learning Automata-Based Congestion Avoidance Scheme uses learning automata based approach to address the congestion in healthcare WSNs. Data packet arrival rate and Packet service rate are maintained equal at nodes adaptively to avoid Congestion in them. The main objective is to learn from the past and improve the performance eventually [23]. Learning Automata (LA) is a mechanism that responds to a sequence of instructions in a certain way to achieve the goal. Variable Structure Stochastic Automata (VSSA) is used in this distributive congestion control scheme in which the action probabilities are updated based on the reward/penalty input from the automaton receivers.

8. Buffer based Congestion avoidance: Light-weight buffer management scheme to avoid Congestion is discussed in (BBCA). The scheme avoids the buffer overflow of the intermediate nodes by adaptively adjusting the nodes' forwarding rates nearly optimal [24]. The authors claim that the near-optimal throughput is maintained at each node and congestion-free load balancing can be achieved through multiple routing paths and to multiple sinks.

Table 2. Summary of the Distributed Congestion algorithms

	Congestion Scheme	**Congestion Control Criteria**
1	CODA	Channel monitoring and back pressure messages
2	ECODA	Packet scheduling with weighted buffer and traffic differentiation
3	FCC	Next-hop node selection using *Optimization* algorithm and efficient route selection using *gravitational search* algorithm
4	DAlPaS	Alternate route selection and routing table is updated
5	PCCP	Hop-by-hop upstream congestion control with priority table
6	DPCC	Rate adjustments for backward and forward nodes based on CI
7	LACAS	Action probabilities are updated based on reward/penalty input from automaton receivers
8	Buffer- based Congestion avoidance	Light-weight buffer management at intermediate nodes

4. CONCLUSION

Congestion control is an important objective in resource limited WSNs as it helps in better throughput, good packet delivery ratio and timely reception of sensed events to accomplish the given task. Many researchers have come up with many congestion control algorithms and this paper presents the various congestion control schemes used in the routing protocols with centralized and distributed strategies. Each method is discussed as how to address the congestion in the network. These existing methods are effective in controlling congestion in the networks and more elaborated methods can be designed.

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