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# A Review on Congestion control Mechanisms in Wireless Sensor Networks

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**Abstract**
Recently, Wireless Sensor Networks (WSNs) have been in many applications and systems with vastly varying requirements and characteristics. Due to this, it would be difficult to decide the requirements regarding hardware issues and software support. Heterogeneous applications can be integrated within the same wireless sensor network with the aid of modern motes that have multiple sensors on a single radio board. Considering such multi-purpose nodes, different types of data could be generated from such types of motes with many transmission characteristics in terms of priority, transmission rate, required bandwidth, tolerable packet loss, delay demands etc. WSNs have many different constraints, such as computational power, storage capacity, energy supply and the most important issue is their energy constraint. Energy aware routing protocol is very important in WSN, but only considering energy has no efficiency in performance.
Congestion in WSNs is one of the critical problems still from its evolution. Congestion causes malfunctions such as packet loss, lower throughput, energy efficiency, increase in collisions, increase in queuing delay and decreased network lifetime. As a result, the performance of the whole network is subject to undesirable and unpredictable changes. In this paper, WSN performance control by robust Congestion control approaches that aim to keep the network operational under varying network conditions is presented.
***Keywords:*** **-** Wireless Sensor Network (WSN), multipath routing protocol, rate reduction, Congestion Control, Rate control, Network Performance.

## I. Introduction

Wireless Sensor Networks (WSNs) [1] consist of one or more sinks and large number of sensor nodes scattered in an area. Sensors have inbuilt capabilities of information sensing, computation, and wireless communication capabilities. Sensor nodes cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations [6] [12]. Sensed data traverse through network towards sink nodes in a multi-hop fashion. They are then sent to the end user from the sink node, either directly or through a gateway [2]. There are two main traffics in WSN namely upstream traffic and downstream traffic. The upstream traffic is many-to-one whereas the downstream traffic is one-to-many. The traffic from sensor nodes to sink node is called upstream traffic [7]. The traffic from sink node to sensor nodes is called downstream. The congestion occurs in node level as well as link level. [13].

### 1.1 Causes for Congestion in WSNs

As the data traffic generated by source nodes nearby sink grows, the offered load exceeds available capacity and the network becomes congested. The main sources of congestion include buffer overflow, channel contention, interference, packet collisions and many-to-one flow nature. Buffer overflow occurs when the number of incoming packets is greater than the available buffer space. Contention occurs between different flows and different packets of a flow. Interference is caused by simultaneous transmissions along multiple paths of the network among the nearby nodes [18] [11]. Packet collisions lead to packet drops, hence lower level congestion. The many-to-one nature of data communication between many sources and sinks results in bottleneck around sink. Congestion causes channel quality to degrade, loss of packets per unit time increases and leads to packet drops at buffers. Therefore congestion needs to be attended.

### 1.2 Types of congestion in WSNs

Congestion in WSNs can be classified in two major categories [14]. First is to concerning to location, second is the causes for packet loss (Fig. 1).

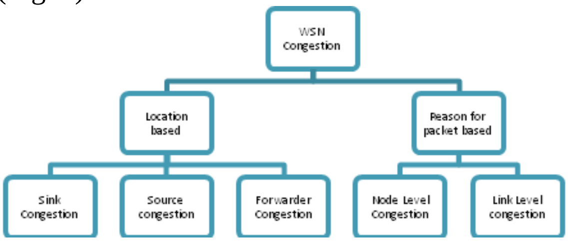


*Fig. 1 Types of Congestions in WSN*

#### *1.2.1 Location based congestion*

## II. Source congestion

Whenever an event occurs, all the sensor nodes within the zone will detect it. These nodes will act as sources for further transmission. Greater the node's radio range, greater is its sensing range. As sources fall in each other's radio range, they can communicate with each other. If all these source nodes, at the same time start sending packets to the sink at high rates, then a hot spot zone will be formed around the sources and within this hot spot a large number of packets will be dropped. This type of congestion can be controlled by careful scheduling between these sources which allows only a small number of nodes (out of all the nodes within the event range) to report to the sink.

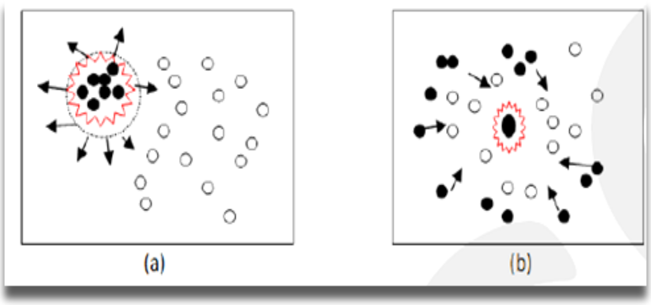


Fig. 2: (a) source congestion and (b) sink congestion.

## III. Sink Congestion

When the sensors observe an event at a high data rate, sink nodes (and the nodes around them) will sense a high traffic volume. If a hot spot occurs around a sink, the packets will be lost inside the congested area near the sink, and dropping of a packet around the sink needs recovery of packets by some means. Another result of side effect is that the battery power of all the nodes that are around the sink will be exhausted quickly, making the sink inaccessible from the rest of the network. Therefore, an effective way of eliminating sink congestion is to place multiple sinks that are equivalently scattered across the sensor field or mobile sink [16].

## IV. Forwarder Congestion:

The sensed data must reach the desired destination by travelling via source and sink nodes and all the subsequent intermediate forwarding nodes. Data in a sensor network will have multiple paths, and these paths will interconnect with one another. The area surrounding the intersection will possibly become a hot spot for congestion. Intersecting flows do not essentially have separate sources and sinks as they can share the same source or sink and hence sharing the segment(s) of the routing path. For example every intermediate node in the tree can suffer from forwarder congestion in a tree-like communication theory (Fig3). Comparing the above two scenarios, Forwarder congestions are more.

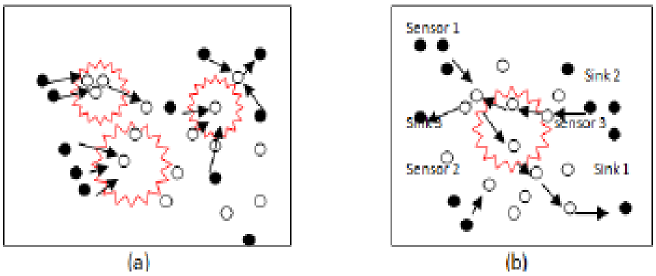


Fig. 3: Forwarder congestion: (a) intersection hot spot merging traffic and (b) intersection hot spot crossing traffic

### 1.2.2 Causes of packet loss

There are mainly two causes for congestion in WSNs [7]. The first case is node level congestion which occurs when the packet-arrival rate exceeds the packet-service rate. This is more likely to occur at sensor nodes close to the sink, as they usually carry more combined upstream traffic. This type of congestion 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 (Fig4(a)).

The second case is link level congestion which occurs due to contention, interference, and bit-error rate. For WSNs where wireless channels are shared by several nodes using CSMA like (Carrier Sense Multiple Access) protocols, 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 (Fig4b). Both, node level and link-level Congestions have direct impact on energy efficiency and Quality of Service(QoS). Hence, the congestion must be efficiently controlled.


Fig.4: (a) node-level congestion and (b) link level Congestion

## V. Congestion control mechanism in WSNs

Congestion control mechanism has three phases congestion detection, congestion notification and congestion control through rate adjustment.

### 2.1 Congestion detection

In case of wired networks, conventional congestion detection techniques depend heavily on packet loss due to buffer overflows to infer congestion, and to a lesser extent on queue occupancy, and end-to-end delay. As energy is the main constrain in WSN, traditional techniques cannot be used. In WSN congestion can be detected by several ways like buffer occupancy, channel sampling and packet service rate and scheduling rate.

### 2.2 Congestion notification

Once the congestion has been detected, the entire network is notified about it in any of the two ways [1]

a) Explicit congestion notification
b) Implicit congestion notification

Using explicit congestion notification, a congested node notifies about the congestion to the rest of the network by explicitly sending the control packet. Sending of this control packet adds significant load to the already congested environment. Therefore, explicit congestion notification has not been used by subsequent congestion control protocols.

In Implicit congestion notification method, congestion information is broadcasted to the rest of the network by overhearing data packets which are on fly. If congestion is detected, a notification bit is piggybacked in data packet's header or in Acknowledgement (ACK) packets (when used). Implicit congestion notification avoids the addition of extra packets to the network when it is already congested.

### 2.3 Congestion control Approaches

Two general approaches to control congestion are [13]

1. Resource management and
2. Traffic control.

Network resource management tries to extend network resource to mitigate congestion when it occurs. In wireless network, power control and multiple radio interfaces can be used to increase bandwidth and weaken congestion. In this approach, it is necessary to guarantee precise and exact network resource adjustment in order to avoid over provided resource or under-provided resource.

There are two general methods for traffic control in WSNs:

**A. The hop-by-hop congestion control:** The hop-by-hop congestion control has faster response. It is usually difficult to adjust the packet-forwarding rate at intermediate nodes mainly because packet forwarding rate is dependent on MAC protocol and could be variable.

**B. The end-to-end control:** The end-to-end control can impose exact rate adjustment at each source node and simplify the design at intermediate nodes; it results in slow response and relies highly on the round-trip time (RTT).

These approaches have been used in many applications such as habitant monitoring [3], image sensing [4] , structural health monitoring [5] etc.

## VI. Classification of congestion control protocols

Several classical congestion control protocols are found in the literature [15]. They can be classified based on i) Rate ii) Buffer iii) Hybrid or Rate and buffer iv) Priority v) Cluster and vi) Multi-path routing (Fig. 5).

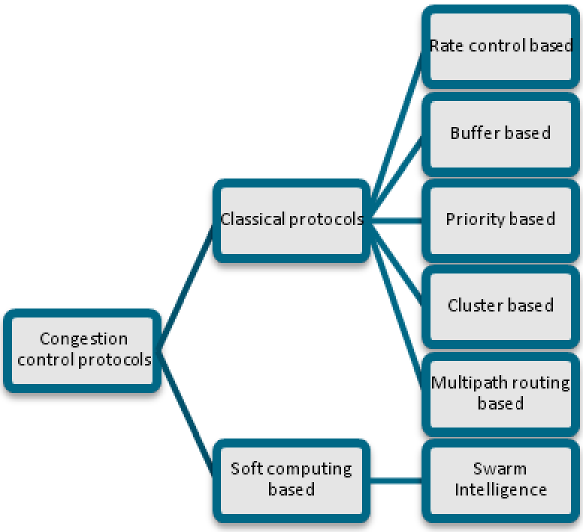


Fig. 5 Congestion control Protocols

### 3.1 Classical Protocols

### 3.1.1 Rate Control Based Protocols

In these types of congestion control protocols, each node estimates the number of flows derived from upstream nodes, and based on this it modulates the rate when congestion is detected. In these protocols, there is a chance that transmission frequency in non-congested source-sink path is reduced, if congestion is detected. Rate control approaches are considered to be the most appropriate when dealing with streaming applications. The protocols that follow this approach are as follows:

1. Congestion Detection and Avoidance (CODA)
2. Event-to-Sink Reliable Transport (ESRT)
3. Pump Slowly, Fetch Quickly (PSFQ)

### 3.1.2 Buffer Based Protocols

Buffer based protocols forward their packets to their upstream neighbors, only when buffer has enough space to hold the packets. It does not consider the data rate of upstream and downstream neighbors. This scheme, unlike the rate based approaches does not drop the packets. The result of these protocols is that, the congestion is alleviated earlier. These methods give the faster detection, and feedback action takes place at right time and they are best suited as reliable methods. Some of the buffer based congestion control protocols for WSN are briefly explained below

1. Congestion Avoidance Based on Lightweight Buffer Management
2. Buffer based Media Access and Greedy Routing Scheme
3. RMST: Reliable Data Transport in Sensor Networks

### 3.1.3 Priority based protocols

In WSNs, different packets may be of different importance in serving of event detection [10]. Since the precision of sensors decreases when the distance grows, the data collected by the nodes closer to the event are usually more precise than those collected by nodes farther away, and therefore more critical to the application when the network fails to transmit all packets to sink, it should try its best to transmit the packets which are more important. Priority can be utilized to describe the importance of the packet or node; congestion control mechanisms include the following link or application [8]. Some of the priority based congestion control mechanisms include the following:

1. Priority-based Congestion control in wireless Sensor Networks (PCCP)
2. Priority based Queue Management (PBQM)

### 3.1.4 Cluster based Protocols

Cluster based congestion control techniques are developed keeping in mind the following aspects: (i) Provision for distributed mechanisms for congestion control and (ii) Management of flows from multiple classes of traffic. In the existing methods, congestion is estimated and action is taken on a per node basis where as in cluster based techniques congestion is monitored in its localized scope. In cluster approach the nodes are divided into various cluster groups and in each group there is one cluster head [9].

1. Cluster-Based Congestion Control for Supporting Multiple Classes of Traffic (CMOUT)
2. Clustering based Energy Efficient Congestion Aware Protocol

3. Cluster Based Congestion Control Protocol (CBCC)

**3.1.5 Congestion Control by Multi-path Routing**

In these protocols, the traffic is transmitted using multiple paths to reach the destination and high priority packets are transmitted prior in the presence of congestion. Hence, these protocols achieve a high degree of reliability.

1. Congestion Aware Routing (CAR)
2. Traffic Aware Dynamic Routing (TADR)
3. Biased Geographic Routing (BGR)

**3.2 Soft Computing (SC)**

SC techniques are smart and intellectual techniques that enhance the effectiveness of WSNs. SC techniques optimize power consumption, network challenges and design and deployment aspects. The European Centre for Soft Computing defines it as "A set of computational techniques to solve problems by imitating nature's approaches". The soft computing paradigms such as Swarm Intelligence (SI), Fuzzy Logic (FL), Game Theory (GT) have been applied to different WSN applications and deployment based on their dynamic and heterogeneous characteristics.

**3.2.1 Swarm Intelligence**

This soft computing paradigm is an evolved system of collective intelligent groups of simple agents that interacts with each other and the environment around. It is characterized with decentralization. Individual agents act by following simple rules that accumulatively lead to global system behavior.

1. Congestion Control in Wireless Sensor Networks based on Bird Flocking Behavior
2. A Swarm Intelligence Congestion Control Approach for Autonomous Decentralized Communication Networks

## Conclusion

In this paper a brief review on causes for congestion, avoidance and control of the congestion is presented. A classification of congestion control mechanisms and the techniques to tackle the problem of congestion in wireless sensor networks from different aspects and situations.

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