Congestion Control in Wireless Sensor Network: Design Issues and Challenges

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Abstract— Congestion control has been considered as one of the major issues in design and development of a communication network. Controlling congestion becomes more critical for wireless sensor networks due to their unique requirements and resource constraints. Network congestion occurs when offered network load exceeds available capacity at any point in a network. Network Congestion cause packet loss, which leads to throughput degradation and energy wastage. Thus it becomes necessary to control congestion in WSNs with an objective to achieve energy-efficiency, fairness and improve the quality of service (QoS) in terms of throughput and packet loss ratio along with the packet delay. There are number of congestion control mechanisms working at the transport layer, data link layer or using a cross-layer approach. The main objective of this paper is to explore the major design issues and challenges related with the congestion control in wireless sensor network.

Keywords— *Congestion Control, Sensor Network, energy efficiency, QoS*

I. INTRODUCTION

Wireless sensor networks (WSNs) is a collection of sensor nodes called as motes, are deployed randomly or in deterministic manner in order to sense the physical environment and process the collected data and then send it to the base station via Internet [1].These motes are miniature nodes equipped with sensing, data processing, and communicating components[2]. Sensor nodes act cooperatively to route data, hop-by-hop towards a central node called sink, or base station using a short range wireless transmission. A WSN comprises a large set of distributed nodes over a wide geographical area to monitor a environmental or physical event. WSN becomes more and more attractive by their integration in a real world of interconnected objects through internet with the emergence of IoT (Internet of Things) [3]. There are several application domains of wireless sensor networks like healthcare [4], target tracking [5, 6], environmental monitoring [7], automatic battlefield [8] etc.

Due to information explosion large amount of data is available to communicate through the communication channels. There are different types of communication networks have been evolved like traditional wired networks, wireless sensor network, mobile network, ad-hoc network, to meet the user requirements of data communication. All these networks are facing the problem of congestion due to huge amount of data. Congestion causes the wastage of communication and energy resources and also hampers the events detection reliability because of packet losses. When large amount of data try to get through a link or node with limited capacity, leads to network congestion. The Congestion can be resolved either by controlling the data rates or by increasing the network capacity [9]. Congestion control in wired network is done by using end to end and network-layer mechanism in concert. Though rate control for WSN is similar to that of wired networks in some aspects, it has unique requirements and restrictions. First, in wireless channel, node can't send and listen at the same time. Second, there's no central station to detect and inform congestion; instead all nodes have similar authority in dealing with congestion. Third, WSN nodes have strict restriction in capacity and energy.

This paper is organized as follows. Section 2 presents an overview of congestion control in wireless sensor network. Section 3 gives a comprehensive view of the evaluation metrics for Congestion Control mechanism in WSN. Section 4 summarizes the design challenges and future directions for Congestion Control Mechanism in WSN. Finally section 5 concludes the paper.

II. CONGESTION CONTROL IN WIRELESS SENSOR NETWORK

Congestion control is one of the important issues that should be considered at transport layer. Due to the event-driven nature of WSNs, resource constraints, many-to-one communications, number of deployed sensors and the high traffic of sensor nodes lead to the creation of congestion in these networks. In WSNs, network congestion occurs when the offered traffic load exceeds the available capacity at any point in the network [10]. Indeed, it can be mentioned that congestion is one of the highly critical challenges in WSNs and it has a profound impact on QoS parameters and the energy efficiency of sensor nodes. Moreover, congestion increases packet loss and degrades the throughput or wireless channels. Thus, in order to handle such challenges and problems in WSNs, researchers should consider and control the factor of congestion.

Congestion control mechanism involves three phases: congestion detection, congestion notification and congestion mitigation. In first phase congestion is detected using different parameters like buffer occupancy (queue length), channel load, buffer occupancy and channel load etc. When congestion occurs, in second phase, upstream sensor nodes are notified about congestion event. Congestion notification can be propagated either explicitly or implicitly. Some congestion control protocols notify the congestion by setting congestion notification (CN) bit in the packet header [24]. Finally in third phase, congestion is mitigated and appropriate data rate is selected, known as rate adjustment or congestion mitigation phase [25]. Congestion mitigation and rate adjustment techniques depicted in Fig. 1, are classified into the following four categories:

i. *Traffic control:* In this method congestion is mitigated by means of reducing the number of packets injected into WSNs at the source node. For ex- CODA, FUSION, ECODA, CCF, FACC etc.

ii. *Resource control:* Here congestion is handled either by increasing network resources or using other idle or uncongested paths for the transmission of data towards the sink. For ex- TARA, LACAS, HTAP, WCCP etc.

iii. *Priority-aware congestion control scheme*: Under this method a prioritized MAC techniques are used to give the congested nodes a prioritized channel access. For ex- PCCP, ACT, DPCC etc.

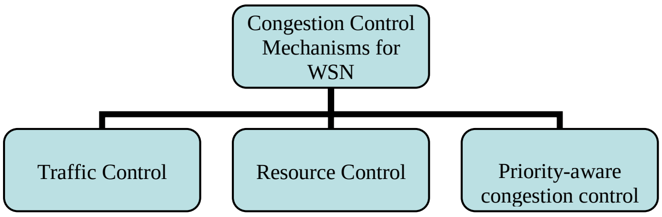

Fig. 1. Congestion Control Mechanisms for WSN

There are number of algorithms proposed under each category by the research community. Effectiveness of these algorithms is measured by using simulation techniques with respect to different performance metrics. The following section of this paper gives a brief overview of some of the major performance metrics used for the evaluation of congestion control approaches in wireless sensor environment.

III. EVALUATION METRICS FOR CONGESTION CONTROL MECHANISM IN WSN

There are several performance metrics while evaluating the effectiveness of a congestion control mechanisms for wireless sensor environment. Some of the major performance metrics for congestion control methods are: packet delivery ratio, throughput, end-to-end delay, hop-by-hop delay, network lifetime, average node energy consumption. Following is the brief review of each performance metric:

i. *Packet Delivery Ratio*: This metric is used to measure the efficiency of the algorithm with respect to the delivery of packets to the sink node. Packet drops are normally measured as the percentage of the total packets that are received by sinks divided by the number of packets that are produced by sources. As the value of packet delivery ratio approaches to hundred percent, indicates that the algorithm is more efficient.

ii. *Throughput*: Throughput is defined as the number of packets per unit time that is received by the sink. The higher the value of throughput is, the more efficient is the algorithm.

iii. *End-to-End Delay*: This metric is used to measure the time that is required for a packet to reach the sink node. This metric is an indication of the efficiency of the algorithm, to quickly mitigate or avoid congestion. The shortest the time is, the better the algorithm’s performance is, since delay normally occurs in congested hotspots due to retransmissions or due to long routes (in resource control approaches).

iv. *Hop-by-hop Delay*: Hop-by-hop delay is also a metric that measures the efficiency of the algorithm in terms of congestion and overhead, since when congestion is avoided, high queueing delays are also avoided.

v. *Network Lifetime*: This metric reflects the long-term energy efficiency of the network. If the power of the nodes is exhausted uniformly then this value increases. This metric is usually high in resource control algorithms.

vi. *Average Node Energy Consumption*: This metric indicates the energy consumption of nodes. The value of this metric should be kept low in order to indicate an energy efficient congestion control algorithm

vii. *Network Efficiency*: quantifies the energy wasted on transmissions that does not deliver packets. The packets dropping cost varies depending on the distance from sink.

viii. *Energy efficiency*: It includes energy spent in channel listening and packets transmissions and forwarding in the whole network. It is also measured per unit of successful communication or received packets [12, 13]. In [14, 15], residual energy is used as the ratio of final energy to initial energy. In [16, 17], energy efficiency has been presented by the delivery ratio.

ix. *Energy Tax*: is defined as the ratio between the total number of packets dropped in the sensor network and the total number of packets received at the sinks [18, 19].

x. *Fairness:* quantifies the degree of variance in sending rates. A fair allocation of bandwidth delivered to the base-station from each node over multiple hops is desirable [16, 17, and 20]. The weighted fairness regarding data priority is introduced in [21, 22]. In [23], node throughput is used as fairness guaranty.

IV. DESIGN CHALLENGES AND FUTURE DIRECTIONS FOR CONGESTION CONTROL MECHANISM IN WSN

There are number of congestion control algorithm have been proposed by researchers for wireless sensor networks. Still some design issues and challenges are there that must be taken into consideration by the research community while designing the congestion control algorithms for wireless sensor environment. Some of the major issues and challenges are depicted in Fig. 2 and listed below:

i. *Lack of appropriate Mathematical Model:* parameters of the algorithms are time-varying in nature due to the largescale characteristic and complex working environment for WSNs. Thus, it becomes difficult to establish an accurate mathematical model for the congestion control problem. The dynamic performance and steady-state performance should be further studied. The stability of the algorithms is lack of theoretical proof [26].

ii. *Robustness against dynamic network environment*: Dynamic changes of network topology are major concern in WSNs. However, the existing congestion control algorithms are lacking in robustness to the environment changes. Existing algorithms rarely consider the interference of wireless links and channel fading influence [26].

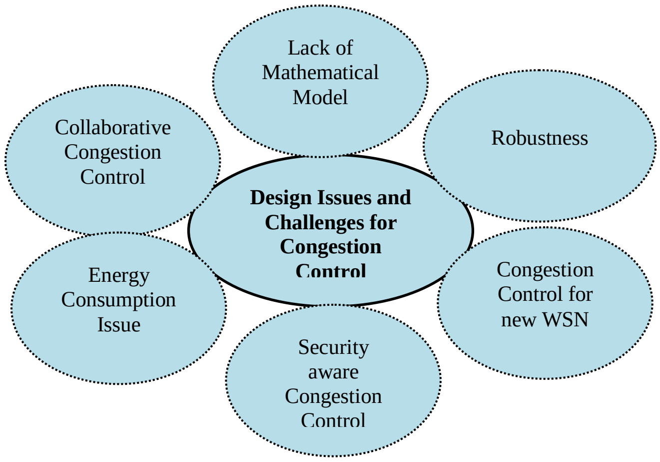

Fig. 2. Congestion Control Issues and Challenges for WSN

iii. *Qualitative and quantitative analysis of the congestion indexes*: There are several parameters like cache occupancy rate, link utilization, time delay, link delay, packet loss rate, recovery time of loss data, packet service time, etc. are proposed to indicate the degree of congestion for WSNs. Most congestion judgment parameters are only based on local information, which only reflect the local state, not global state of the network. In addition, the performance of cost, congestion detection sensitivity, precision and detecting speed is not specifically considered in these indicators. Thus the qualitative and quantitative analysis of the congestion indexes needs further investigation [26].

iv. *Collaborative Congestion Control:* The implement of congestion control mechanism needs the collaboration of other mechanisms to enhance the performance. Therefore, congestion control mechanism should be designed with a global vision. Congestion control based on cross-layer design and optimization can enhance the applicability of the congestion control algorithms. Cross-layer approach can be used since it is able to interact with different layers such as prioritized MAC, reliable transmission, etc[26].

v. *Intelligent Algorithms and Optimization Methods for Congestion Control in WSNs:* The traditional centralized algorithm and end-to-end control mechanism are inappropriate for WSNs. Many new intelligent algorithms and optimization methods are put into application of the congestion control in WSNs. The distributed algorithms achieve good performance as congestion may occur at local level, and data transmission path is dependent on the state of neighbour nodes. When designing the algorithms, adaptability must be ensured to adapt the time-varying of the network. Some algorithms achieve good performance by using intelligent algorithm to adjust parameters dynamically [26].

vi. *Energy Consumption Problem in Congestion Control for WSNs:* Energy constraints are a major concern in the creation of algorithms for WSNs [27]. Balance of energy consumption and improvement of energy utilization efficiency are important problems for congestion control in WSNs. The simulation results in paper [27] show that the rate adjustment mechanism shortens lifetime of the network as it fails to balance the energy consumption. The routing optimization mechanism can make full use of the nodes to avoid the excessive energy consumption of a unique node. The mechanism could significantly prolong the survival time of the network [26].

vii. *Security aware Congestion Control*: Security is considered as one of the crucial issue for several applications in wireless sensor networks. An illegal and erroneous interference might bring about catastrophic consequences. Thus, the possible interactions between congestion control and security should be the subject of future studies. Moreover, it is essential that researchers develop novel approaches and methods which are aimed at protecting congestion control protocols against malicious nodes or an adversary. Hence, future researchers should zoom in on this security problem and try to sort it out [25].

viii. *Congestion control for new WSNs:* The impact of enhancing multimedia (audio/video) applications for WSNs on congestion control is regarded as a potential direction for further research. Thus, this effect should be taken into consideration in future studies. Emergence of newer WSN generations such as Wireless Multimedia Sensor Networks (WMSNs), Body Area Sensor Networks (BASN), and under-water Sensor Networks (UWSNs) has framed newer issues and challenges for design and implementation of appropriate congestion control protocols [25].

V. CONCLUSION

In this article, we summarized the congestion control problem which occurs in WSNs. In WSNs congestion control protocols are classified into three categories: traffic based; resource based and priority based. This work explores the major issues and challenges of congestion control algorithms in the context of wireless sensor networks. Throughput, fairness, energy efficiency, end to end delays, energy consumption, network lifetime and packet delivery ration are some of the major design and implementation issues for congestion control approaches in WSNs. We also point out the research hotspots and difficulties in this area which need to be further studied. The identified issues and challenges regarding the WSNs congestion control algorithms may help in future research in this area.

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