RESEARCH ARTICLE

Congestion Control in High Density Wireless Personal Area Networks.

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Manuscript Info	Abstract
	Congestion control is considered to be one of the most significant challenges in Wireless Sensor Networks (WSNs) which is attributed to resource constraint specification and the number of deployed nodes. In WSNs, congestion is caused by the following factors: packet collision, node buffer overflow, transmission channel contention, transmission rate, many-to-one data transmission scheme and dynamic time variation transmission channel. Indeed, congestion has a significant impact on packet delivery ratio (PDR), end-to-end delay and energy consumption. When nodes are densely distributed or due to high flow rate, congestion of data packets are bound to occur which leads to packet loss, inefficiency and lack of fairness. Hence congestion needs to be controlled. Here we are considering throughput degradation problem in WSNs due to congestion occurring in highly dense scenario. This paper proposes hop by hop congestion control protocol named UHCC which works in upstream direction i.e. from source to sink. Simulations show that there is significant improvement in Throughput and PDR.

Introduction

Wireless Sensor Networks (WSNs) are having very wide range of applications nowadays and their deployment in near future is expected to increase since it provides a low cost service regarding both installation and maintenance. Wireless sensor networks consist of distributed autonomous devices which uses sensors to monitor physical or environmental conditions such as temperature, pressure, sound and vibrations. They are made from nodes. Each of them has transceiver having antenna, microcontroller and battery. The available wireless standards include IEEE 802.15.4 or IEEE 802.11 (Wi-Fi) standards.

IEEE 802.15.4 WPAN Standard:-

IEEE 802.15.4 is one of wireless standards which have diverse applications. As the name indicates LR, its goal is to provide low power, cost effective, flexible and scalable wireless networks [1]. Data transfer rate of these networks is 250 kbps and it can support up to 65,536 nodes [2]. This number is about to increase in near future as well. This large no. of nodes allows the network to have applications in areas like healthcare, surveillance, industrial, automation, smart home, remote sensing, structural health monitoring, and many more[3][4].

LR-WPAN operates in either of two topologies: the star topology or the peer-to-peer topology [1].
In the star topology, the communication is established between devices and a single central controller, also called as the PAN coordinator. The peer-to-peer topology also has a PAN coordinator; however, it differs from the star topology in a sense that any device can communicate with any other device as long as they are in radio range of one another. Peer-to-peer topology allows more complex network formations to be implemented, such as mesh networking topology.

Effect of Congestion on WSN:-

WSNs suffer from limited resources like storage, computation, bandwidth, and most significant of all energy. These restrictions affect QoS parameters such as packet delivery ratio, end-to-end delay, bandwidth utilization and average node energy consumption in WSNs [5]. Like any other network in WSNs congestion occurs when offered traffic load is much more than carrying capacity of network [6][7]. Sensor network is a network consists of computing devices that gives an ability to monitor and react to events and in a particular environment. This network can be used in civil, commercial, governmental, healthcare and industrial applications. The general structure of wireless sensor network is like tree so what happens that all the data which is generated at the sensor nodes moves toward the sink node. Due to this nature of wireless sensor network there is very much chances that congestion will occur in near sink node. As congestion affects on different parameters like it can cause decreasing packet delivery ratio, decreasing overall throughput of system, causing retransmissions due to packet loss, Congestion control is very important.
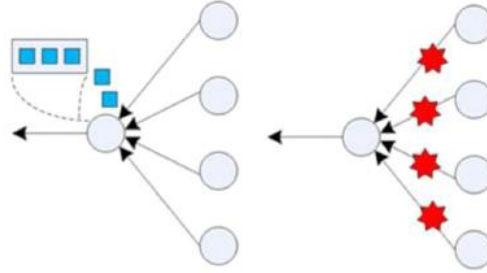

Fig.1:- Types of Congestion in WSN

Types of Congestion- Node Level and Link level [8] as shown in fig.1 Node level congestion takes place when packet arriving rate is more than packet service rate. Nodes which are more near to sink have to suffer most by this type of congestion. Consequences of this type of congestion are increase in packet loss, wastage of power resulting in network availability & network lifetime. Reasons for link level congestion are competition to get hold o f the channel resulting in packet collisions and bit error. Due to this packet delivery rate at the sink node is reduced.

Rest of the paper is organised as follows: The related wok is presented in section 2. Section 3 describes the proposed work. Working of traffic shaping algorithms is discussed in that section.   Results are discussed in section 4 and the paper is concluded in section 5.

Related Work:-

Congestion control [8] in WSN is done in three steps: congestion detection, congestion notification & congestion control.

Congestion Detection:-

It is the process of detecting & finding the presence of congestion in network. Congestion detection in WSN depends on following parameters:

Buffer Occupancy- it is the queue length of the node and when it is filled it indicates congestion.

Channel load- it is another parameter which helps in detecting congestion as it results in increase in time frame for the transmission of data packets than predefined threshold.

Packet Service Time- it is defined as the time difference between packet arrival at MAC layer & its transmission time.

Congestion Notification:-

It is the process of informing the upstream nodes about collision situation in network. There are following two methods of congestion notification:
1. *Explicit Congestion Notification-* this technique involves making use of sending special control messages to upstream sensor nodes. This mechanism results in further increase in link load due to more control messages.
2. *Implicit Congestion Notification-* in this technique the congested node will inform about congestion by piggybacking the congestion information in a payload packet header.

Congestion Control:-

The various congestion control techniques [10] can be broadly divided into four categories as shown in figure 2
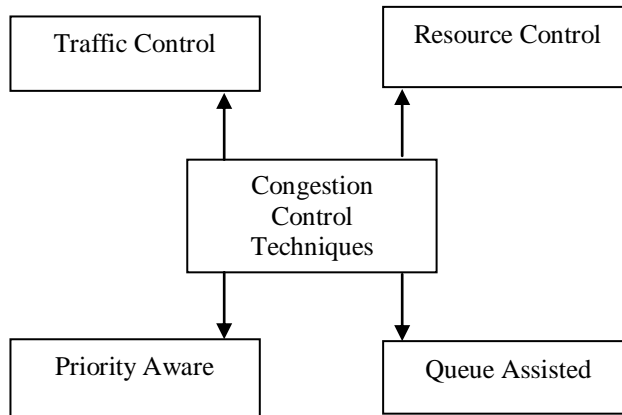

Fig.2:- Types of Congestion Control Techniques

CCF in WSN [9] actually concentrates on the assigning fair and efficient transmission rate to each and every node. It adjusts traffic rate based on packer service time along with fair packet scheduling algorithms. Thus it is traffic control technique of congestion control. The average output traffic and average input traffic of each node is monitored. CCF algorithm each node measures the average rate r at which packets can be sent from the node, divide the rate among the children nodes, adjust the rate if the queue is overloaded and propagate the rate downstream. 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.

The rate adjustment is based on packet service time which leads to low utilization as it has significant packet error rate. It cannot allocate the remaining effective capacity as it uses work-conservation scheduling algorithm [9][10]. Also as it contains the feedback mechanism so it will introduce the delay for it. In resource control mechanisms, the congestion is handled by managing the hardware resource available i.e. increasing network bandwidth or using idle or uncongested path for transmitting packets or based on available energy. This technique improves packet delivery rate significantly.

DA1PaS [11] i.e. a performance aware congestion control algorithm in wireless sensor networks chooses alternate path if there is congestion.DA1PaS considers the energy consumption, congestion level as well as nodes remaining power to take the decision of the alternate path. For Setup phase the algorithm proposes a technique by using which the level of each and every node is found out and neighbour table is updated.DA1PaS mechanism after setup phase is divided into two stages: soft stage and hard stage. In soft stage DA1PaS tried to receive data at one node from one flow only as flow from multiple node can cause congestion. This can be achieved by finding alternate paths. The hard stage is the stage where the network forces the flows to change direction in one of the three cases. (i) Buffer occupancy is reaching its upper limit or (ii) low remaining power or (iii) higher level node unavailability in hard stage algorithm first flag decision algorithm is run. The algorithm is dynamic so the number of hops to sink to the node may change in the processing of this path selection algorithm. The next node to forward the data is found out based on its availability and number of hops from the sink. It sorts all the available nodes based on the hop distance and remaining power from the sink node and the least distance node is selected as the next node.

C. Sergiou et. al [12] proposed a resource control scheme of controlling the congestion. It creates alternative paths from source to sinks. Local information such as path switching is used for path switching decision. It consists of four different schemes: 1. Topology Control, 2. Hierarchical tree creation, 3.Alternative Path Creation, 4.Handling of powerless nodes. HTAP needs to address problems arising from redundant number of nodes and their dense deployment. Topology control scheme serves this purpose in order to maintain performance characteristics of network. Hierarchical tree creation scheme uses topology control scheme and mainly works on two steps. 1. Path creation- Hierarchical tree is created at source nodes. 2. Flow establishment- Each transmitter and receiver are connected using two way handshake. Alternative path creation brings itself into action when congestion at particular node is about to occur. This helps to control hidden and exposed terminals problem. Power or energy remaining in node is considered by fourth and last scheme used in HTAP i.e. handling of powerless nodes. Power extinction threshold is set and

whenever this limit is reached node informs about this to neighbouring nodes. If in case, power drained node is a part of active path from sources to sinks then alternative path is selected.

DPCC[13] that uses rate control adjustment, back-off interval selection and distributed power policy for congestion control at each of the WSN nodes. The DPCC considers buffer occupancy at each node for congestion detection. Once congestion is detected, the backpressure message is generated to diminish congestion on the basis of hop-by-hop estimation of traffic flow. The priority based congestion control by Wang et al. (2007) [14] introduced the concept of node priority index. The scheme is upstream in nature and is designed for many to one communication. The scheme is based on Intelligent Congestion Detection (ICD). The ICD detects congestion based on packet inter-arrival time and service reflecting congestion level along with detailed information. The Implicit Congestion Notification (ICN) is responsible for piggybacked congestion information in the headers to avoid control flow overhead. The priority based rate adjustment (PRA) indexes the nodes based on priority. The index value determines the bandwidth allocated to each node.

Proposed Work:-

In general, wireless sensor network has a tree like structure. So, all the data gathered by sensor nodes will move towards sink node. Due to this behaviour of WSNs chances of occurring congestion in near sink nodes are very much higher. Hence in UHCC i.e. Upstream Hop-by-hop Congestion Control protocol, congestion detection and rate adjustment are done in order to decrease packet loss and to increase throughput [15].

Mathematical Model:-

Let us consider the N sensor nodes in which for congestion detection we are using the following expression where C(i) is a set of child nodes of node i and P(i) is a set of parent node of node i. So for congestion detection metric (congestion index) calculation is done as follows.

$$CI_i = Buffunocccupancy^i - Tr^i$$

$$Buffunocccupancy^i = BS_{max}^i - BS_{occupancy}^i$$

$$Tr_i = r_{si} + \Sigma \; r_{ji} + \Sigma \; r_{ik} \qquad Where \; j \in child(i) \, , \; k \in parent(i)$$

Based on the congestion index value the rate adjustment is done.

In UHCC hop by hop congestion control is done so every hop calculates the congestion index. And if the congestion index is negative there are chances of congestion. UHCC then checks whether there will be congestion in child node in the next interval if we suppress the traffic from the child node to the parent node. And based on that congestion tendency is calculated. If the congestion tendency is negative then there may be chances of congestion. Based on the aggregate of these negative congestion tendency of child nodes congestion tendency of the parent is calculated. Now UHCC checks whether node have the traffic capacity to handle this condition for that it calculate the traffic capacity as the total of buffer un-occupancy and the traffic which will go to its parent in the interval. Now the difference between the traffic capacity and congestion tendency will tell you whether there will be congestion or not. If the value is negative it tells you that there will be congestion so the node doesn't allow its source traffic and rate adjustment on transit traffic will be done. Larger the value larger the traffic rate is allocated to the child node. If the congestion index is not negative the rate adjustment is done to improve the performance of the system. While doing the rate adjustment it always considers the source traffic priority.

First the congestion tendency is calculated.

$$CT_{ji} = CI_j - r_{ji} * T \qquad where \; J \in C(i)$$

So it suppresses the traffic from the child node j to node i and checks whether there will be congestion or not.

Then using CT_{ji} absolute value of congestion tendency is calculated as follows

$$CT_i = \Sigma \left| CT_{ji} \right| \; for \; all \; CT_{ji} < 0$$

After this traffic capacity is calculated as follows

TC_i = Buffunocccupancy$_i$ + Σr_{ik} Where k $\in$ parent (i)

Now to decide whether at the child node the current rate is supported by the traffic capacity or not the TC_i' is calculated

$TC_i' = TC_i - CT_i$

Now based on this parameter the rate adjustment is done

If $TC_i' >= 0$ then

$rs_{new} = PR_s * TC_i' * 1/T$

$(\mid CT_{ji} \mid + PR_{ji} + TC_i)*1/T$ if ($CT_{ji} <0$)

$Rji_{new} = PR_{ji} * TC_i' * 1/T$ if ($CT_{ji} >= 0$)

If $TC_i' < 0$ then

$rs_{new} = 0$

$(\mid CT_{ji} \mid / CT_i)* TC_i *1/T$ if ($CT_{ji} <0$)
$Rji_{new} = 0$ if ($CT_{ji} >= 0$)

Simulations and Results:-
The algorithm is implemented in NS-2 [16] with the simulation parameters shown in the table 1.
The Wireless Personal Area Network with Cluster Tree topology is implemented to test the algorithm. Simulations are performed and various parameters were recorded.

Table1:- Simulation Parameters

Parameter	Value
MAC Layer Protocol	**IEEE 802.15.4**
Packet Size	**120 bytes**
Buffer Size	**80 bytes**
Number of Nodes	**10 to 100**
Environment Size	**300 m × 300 m**
Routing protocol	**AODV/UHCC**
Simulator	**NS 2.34**

Number of Nodes Vs. Throughput:-
As we can see in fig.3, as number of nodes are increasing throughput is also increasing. But at certain point (when number of nodes is 50 and 80), throughput starts degrading, since both types of congestion i.e. node level and link level comes to the picture. Red line graph is showing throughput after implementing proposed UHCC protocol. We observe increase in throughput even though numbers of nodes are increased up to 100.
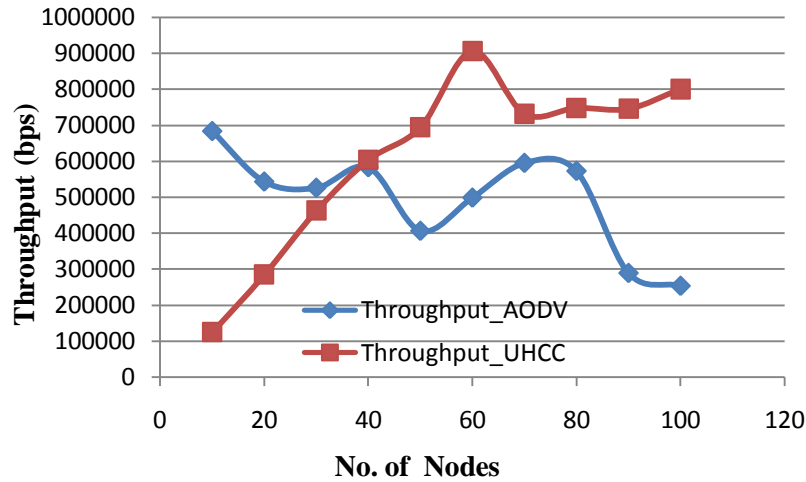
Fig.3:- Number of Nodes vs. Throughput (bps)

Number of Nodes Vs. Packet Delivery Ratio:-

Fig.4 shows packet delivery ratio plotted against number of nodes. As node density goes on increasing packet delivery at the sink reduces. One of the important goals of any congestion control algorithm is to enhance this packet delivery ratio at sink. Simulations show that by implementing UHCC protocol PDR increases by around 40% as shown.
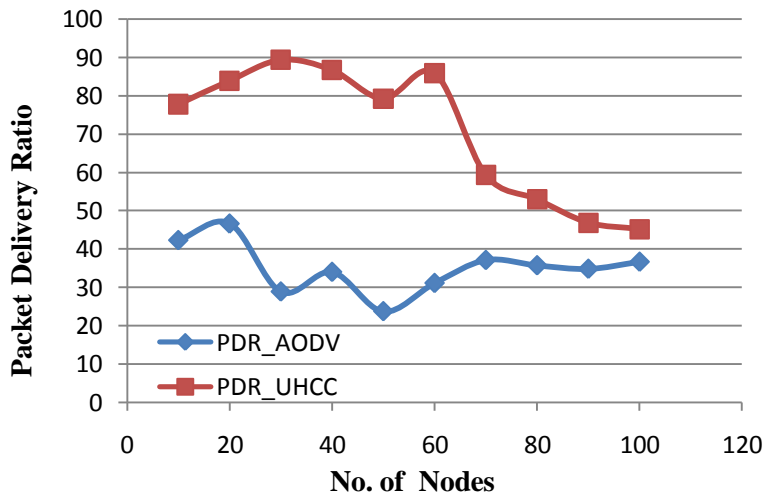

Fig.4:- Number of Nodes vs. Packet Delivery ratio (in %)

Number of nodes Vs. Average Delay:-

As we can see fig.5 average delay is varying constantly in case of AODV protocol. Actually it should get increase as number of nodes increased. But since AODV maintains routing table very efficiently delay in delivery packets from source to destination decreases as number of nodes are increased. However we can see that proposed UHCC protocol has very less average delay and it remains almost constant.
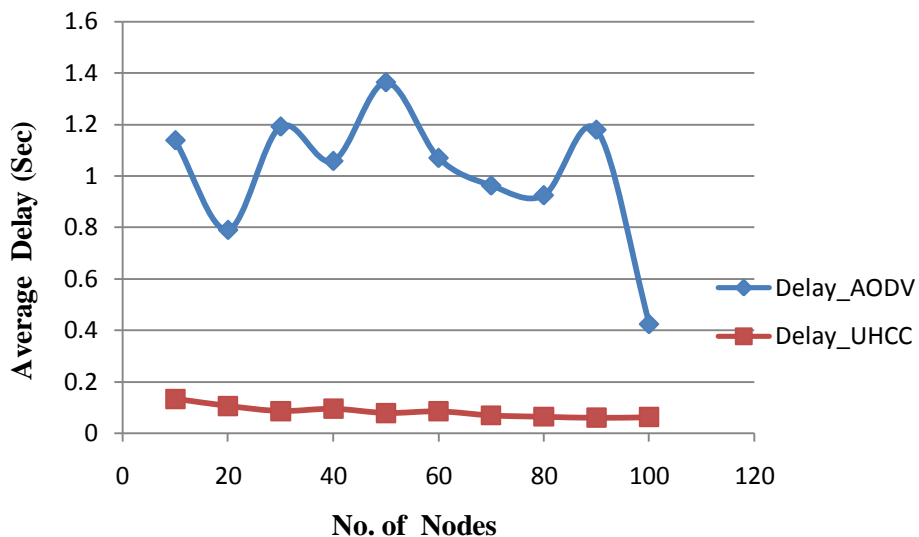
Fig.5:- Number of Nodes vs. Average Delay (in seconds)

Number of nodes Vs. Jitter:-

Jitter is defined as a variation in the delay of received packets. The sending side transmits packets in a continuous stream and spaces them evenly apart. Because of network congestion, improper queuing, or configuration errors, the delay between packets can vary instead of remaining constant. As we can see in figure 4.8 this variation in delay i.e. jitter is less in presented work of UHCC than AODV.
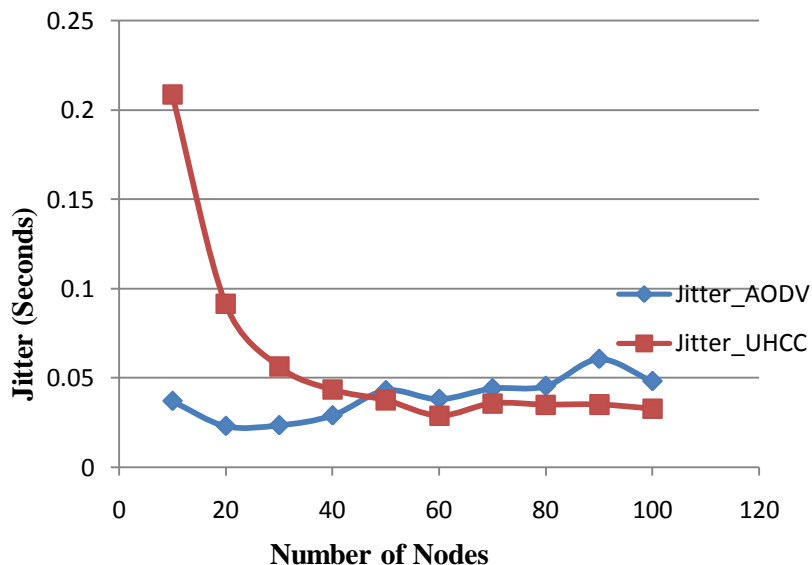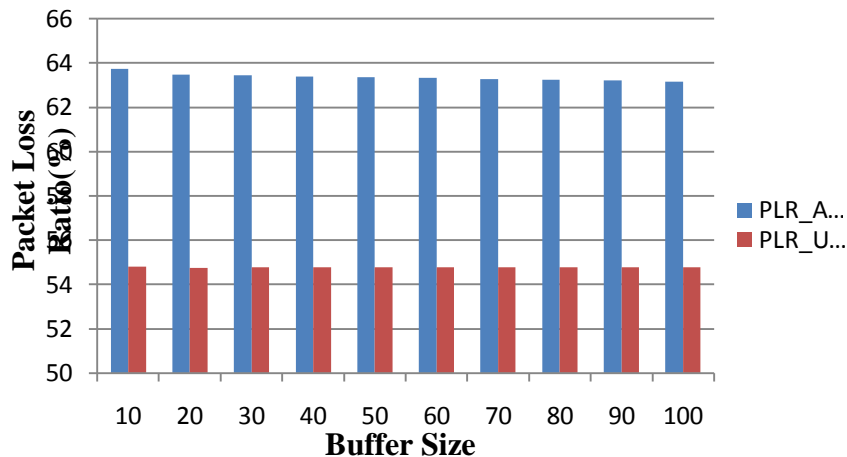

Fig.6:- Number of Nodes vs. Jitter (in seconds)

Packet Loss Ratio Vs Buffer Size:-

As we can observe from fig.7 packet loss ratio is almost constant for both AODV and UHCC implementations. But UHCC has less packet loss ratio than AODV at least by 9 percent. This graph is plotted for 100 node scenario. Hence we can say that UHCC gives better results in high density scenario.

Conclusion:-

Proposed algorithm is controlling congestion in WSN. Network performance parameters are compared without and with congestion control. We have used AODV routing protocol to compare with proposed UHCC routing protocol. The Packet delivery decreases to the greater extend. There will be large number of packets will be lost with this and the delay will increase as the number of retransmissions increase so we must control the congestion. Proposed algorithm increases packet delivery ratio resulting in increased throughput is achieved with the proposed technique.

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