**Congestion Control Avoidance in WSN**

**1.- Congestion in WSN**

* Congestion in wireless networks may be **caused** due to the following reasons: contention caused by concurrent transmissions, buffer overflows and time varying wireless channel condition.
* In WSNs congestion may be **distinguished** in two different types: the node level congestion and the link level congestion.
* **Node level congestion** is common in typical multi-hop networks. It occurs in situations where the buffer of an intermediate sensor overflows. Node level congestion results to an increase of both packet loss and delivery time. Most of proposed protocols try to avoid this type of congestion.
* **Link level congestion** is usually caused due to collisions caused by simultaneous transmissions of neighboring nodes. Link level congestion can result to increased packet loss due to packet collisions, increased packet time delivery and decreased channel utilization and overall throughput. When this type of congestion occurs is quite possible that node level congestion will occurs at a neighbour node.
* **Congestion control** studies recovery from congestion methods and prevents network from collapsing
* **Congestion avoidance** studies methods to prevent congestion. In this paper we focus on congestion avoidance.

**2.- Mechanisms for Congestion Detection**

1. **Queue occupancy**: If a node receives more data than it can forward, the additional data has to be stored in the limited buffer space. In order to avoid buffer overflow each node in the network should monitor its residual-buffer space and when it exceeds a pre-defined threshold, then the node has to inform its upstream neighbors. Then the upstream neighbors have to reduce their sending rate towards to that node and even better to avoid using that node as intermediate.
2. **Channel utilization**: It refers to use CSMA protocol

**3.- Mechanisms for Congestion Avoidance**

1. **Popularity of node:** This proactive mechanism uses metrics and weights in order to determine the popularity of node. Popular nodes usually are the nodes located close to the sink (bottlenecks) and these nodes that have many children in a span-tree topology. The popular node has to remain awake continuously in order to receive the incoming traffic. It results to both congestion and waste of energy. Therefore the source node has to avoid forwarding the sensed data through popular nodes to the sink in order to avoid congestion.
2. **Multipath routing:** It can be used as a proactive congestion avoidance mechanism. Apart from that, multipath routing can also be used as reactive mechanism in case of a congested path.
3. **Rate limiting:** Rate limiting is a reactive mechanism.

**4.- Congestion Avoidance Protocols**

* **Congestion avoidance protocols** differ on the way which detect and avoid an upcoming congestion.
* **Congestion control protocols** do not consider the packet loss.
  1. **PACA (Popularity Aware Congestion Avoidance)**
* It aims to **identify** upcoming congestion and **prevent** its further diffusion.
* **Prediction of congestion** is based on a cost function, which considers a set of metrics related with the popularity of the alternate nodes and routing paths.
* These metrics are: 1) the distance between the node and the base station. Nodes located close to the base station, are associated with a greater probability to be intermediate routers of data transmitted from more distant nodes to the sink. 2) The ratio of the total number of the neighbours of a node over the number of its upstream neighbours. Nodes having less upstream than downstream neighbours are theoretically associated with a greater probability in order to receive more traffic than they can forward. 3) The total time of the node participation in communication flows. Nodes located at position closer to the areas that often incidents occur, have increased load, due to the fact that they have to transmit many event-based reports to the sink.
* The popularity cost can be calculated for each node individually and for every corresponding potential path. The node or the path with the lowest popularity cost gets preferred to forward data towards the base station
* **Prevention of congestion diffusion** is carried out through multi hop, multipath routing, by utilizing nodes and routes which are less popular and as a result less probable to be congested.
* **Disadvantages:** 1) **It algorithm results to an increase of delay** due to the fact that nodes belonging to shorter paths have higher popularity cost than the others, thus forwarding nodes prefer paths which include more hops to the sink.
* **Advantage:** simulation results showed that **PACA provides a particularly efficient method for congestion avoidance.**
  1. **Congestion avoidance based on lightweight buffer management in sensor networks**
* It tries to adapt the sensor’s forwarding rates to nearly optimal without causing congestion.
* It makes sure that a node y sends a packet to another node x if and only if x has sufficient buffer space to hold the packet.
* Each node stamps its current buffer state in the frame header.
* In order to tackle the hidden terminal problem, each node advertises only a proportion its buffer (k-buffer solution).
* Nodes catch the current state of theirs neighbors by receivers or overhead packets.
* **Disadvantages:** 1) Increased energy consumption, since it protocol based on overhearing. 2) Increased delay because the k-buffer solution does not utilize the full of the available buffer space.
  1. **Congestion Avoidance and Fairness in WSN**
* It propose a congestion avoidance scheme with multipath routing for WSNs using the CRi (Characteristic Ratio) value (i.e. the ratio of downstream and upstream nodes for a particular node i) and the queue occupancy.
* Each node has to maintain a neighbor table, which contains the number of node‘s upstream and downstream neighbors, and the current buffer size of downstream neighbors.
* Nodes forward packets to great CRi and reduce forwarding rate for nodes with less CRi.
* If CRi is one, the node must choose the candidate downstream node with the smallest queue size
* The information about the current buffer size of each node is piggybacked in data packet’s header in order to neighbouring nodes update their neighbour table’s filled.
* **Disadvantage:** This protocol result in increased packet-drop rate. Also, the protocol is totally proactive without taking into consideration the current situation in network.
  1. **Congestion Avoidance and Fair Event Detection in WSN**
* It tries to grant proportionate access to the medium at each upstream node in order not to overwhelm the capacity of downstream nodes.
* Each node in the network is characterized by its source count
* This protocol contains three components:
  1. Hierarchical Medium Access Control (HMAC). This algorithm grants medium access to nodes proportional to their source count value.
  2. Weighted Round Robin Forwarding (WRRF). Upstream nodes forward data to downstream nodes if and only if is, has sufficient buffer space. In addition each upstream node of a downstream node forwards its data to downstream node in round robin scheme.
  3. In-Node Fair Packet Scheduling (FPS). This mechanism guarantees that a downstream node will forward packets received from each of its upstream nodes prioritized with their source count values.
* To accomplish this, the downstream node maintains separate virtual queues for each of its upstream nodes and a queue for the empty buffer management.
* To avoid congestion, it purpose two different schemes:
  1. Hard congestion avoidance. The downstream node should forward all received packets from a round robin round before it begins a new one. **Vantages:** This scheme guarantees zero buffer drops but decrease network throughput
  2. Soft Congestion Avoidance. The downstream node begins a new round of round robin as soon as possible without the above restriction. The downstream node estimates the residual buffer space required for the next round, and when this space is available, the node begins the next round.
* **Disadvantages:** The upstream neighbours do not know exactly when each round robbin starts. So they have to stay awake in order to be informed about that.
  1. **MR-CACM (Multiple Paths Routing – Congestion Avoidance Control Mechanism)**
* The **parameters related to nodes** are: 1) utilized ratio of buffer (BOi), 2) Load factor (LFi): the ratio of the sum of all the inflow velocity to the sum of all theoutflow velocity. 3) Utilized frequency of node (Ui): the number of paths using node i and 4) Residual energy of node (Ei).
* **The parameters related to paths are:** 1) Utilized ratio in path (BOp): the max of the buffer utilized ratio BOi 2) Load Factor (LFp): the max of the load factor (LFi) and 3) Utilized frequency of path (Up): the max of Utilized frequency (Ui).
* The source node in order to select the paths to forward its data towards to the sink, sends route-finding request information and the node receiving that, sends PREP (path response) to source
* **Disadvantages:** 1) Overhead: In the process of constructing paths several messages are exchanged between nodes. 2) In hard congestion existence, a downstream node may not be able to inform its upstream neighbours about the congestion because of collisions.
  1. **CAEE (Congestion Avoidance and Energy Efficient)**
* It utilizes the sink mobility along a fixed trajectory and an in-network storage model that is used to set up mini-sinks along the mobility trajectory of the sink.
* In-network storage model is based on a clustered sensor.
* When the buffer at a cluster head reaches a threshold, because the cluster head fails to forward the collected data due to congestion, then the node selects a sleeping node i and starts to redirect to i node all of its incoming data. If i’s buffer becomes full, the cluster head selects another sleeping node to redirect the incoming data.
* When congestion is eliminated the cluster head collects the data from buffer nodes and forward that to the sink.
* Mini-sinks are clusters located along the mobility trajectory of the sink.
* Cluster head is responsible for data collection at each mini-sink.
* Cluster heads which do not belong to mini-sink have to collect and forward their data to the nearest mini-sink.
* The mobile sink stops at each mini-sink and request data transfer from the cluster head.
* **Disadvantages:** 1) mobility trajectory of the sink, along the periphery is not suitable for large WSNs because the time interval between two successive stops of mobile sink at the same mini-sink will be very large, thus the data will not be 2) Mainly at outdoor applications if an obstacle blocks the sink, the network will collapse.
  1. **DAIPaS (Dynamic Alternative Path Selection Scheme)**
* It increasing capacity while attempting to maintain performance requirements.
* It tries to choose an alternate routing path in order to avoid a congested node, taking into account: critical performance parameters such as the remaining power of nodes, the available buffer space, the medium interface and the node’s distance from the sink.
* In the setup phase the nodes are separated into levels according to their distance from the sink.
* Each node in the network maintain a neighbour table, which consists records for the ID of its neighbours, their buffer occupancy, their residual energy, their number of hops to the sink and a field ”Flag”, which indicates the node’s availability at the current moment.
* **If congestion doesn’t exist**, the node forwards its data packet through the node that provides the shortest route to the sink.
* An ACK packet. Its header contains, receiver’s ID, next packet sequence number, buffer occupancy, remaining power, number of hops away from sink, and flag.
* When a node receives or overhear an ACK packet modify their neighbour table with the updated values.
* DAIPaS scheme employ two stages, soft and hard.
* When a node receives packets from more than one flow. It is associated with greater probability to be congested. So, the node sets the field ”Next Packet Sequence Number” in the ACK packet header to ”False” for the specific node ID that would like to stop its transmission.
* The node enters in the hard stage due to its buffer occupancy is reaching its upper limit, its residual energy, so the receiving nodes force the sender nodes to stop transmitting towards them, by setting their flag field to”False».
* Sender nodes choice alternative paths, this choice depends on the node’s availability and the number of hops to the sink and buffer occupancy.
* **Disadvantages**: 1) Increased energy consumption. The protocol based on overhearing, which has as a result the RF transceiver being open for long times. 2) In hard congestion existence, a downstream node may not be able to inform its upstream neighbours about the congestion because of collisions.
  1. **GMCAR (Grid-Based Multipath with Congestion Avoidance)**
* It’s a proactive, hierarchical[[1]](#footnote-1) and multipath routing protocol for WSNs.
* The functionality of GMCAR is divided into three phases
* **1) Grids formation phase**. The network field is divided into logical squared-shaped grids of a predefined size. A Global Positioning System (GPS) is used to determine to which grid every node belongs and a node with highest ID is selected as master node, which is responsible to routing the data generated in the grid or received from the neighbour grids. When master node’s energy is about to drain, it starts an election process to select a new one, based on the residual energy.
* **2) Building routing tables phase**. The authors assume that the sink locates in one of the topology corners, so that the grids are divided in two types: Boundary grids and no boundary grids. The sink broadcasts a flooding message in order to determine whether master nodes belong to a boundary grid or not, and moreover to maintain their routing table. The flooding message consists of seven fields: 1) Sink location field, 2) Total number of grids, 3) Grid ID, 4) Master node, 5) Boundary, 6) hop count and 7) Grid density (number of nodes in grid). Any master node that receives this message, creates entry/entries in the routing table according to the information carried in the message, updates the flooding message field and rebroadcasts the message. Non-boundary grids utilize multiple diagonal paths towards to the sink, whereas the boundary grids utilize single vertical or horizontal path towards to the sink.
* **3) Data Transmission phase**. The master node of each grid collects the data from the rest nodes in the same grid and then selects the suitable master node to forward the data to. The master node assigns a weight for every forwarding candidate, which is a function of both the Hop Count and Grid density. The route that has the highest grid density and the smallest hop count is the preferred one. In addition to, a Priority field is added to theheader of packet, which indicates whether a packet is for real or non-real time application. Real-time packets are forwarded along the shortest path route, while the rest arerouted along the highest weight link path, reducing the energy consumption.
* GMCAR also contains Congestion Avoidance and Congestion Mitigation Mechanisms. The proposed congestion avoidance mechanism is based on queue occupancy. When master nodes’ buffer exceed a threshold, the congested node broadcasts ”route invalid” message to the neighbouring nodes, and the latter must change their routing paths, in order to avoid packet drops. So electing a secondary node, based on the residual energy of the candidates, so that the load is distributed between the master node and the secondary master.
* **Disadvantages**: 1) Authors assume that each master node of every grid is able to connect with a master node from a higher level grid. This isn’t realistic. 2) Acting a sensor as master node until its energy is about to drain results in quicker network partitioning.



**5.- Discussion**

1. **Types of upstream data traffic**

* **In Query based delivery and Event based delivery.** it is impossible for a proactive algorithm to predict and tackle an oncoming congestion. On the other hand a reactive algorithm, which monitors the current network state (i.e. node’s queue occupancy), has the ability to predict the forthcoming congestion and enable the corresponding mechanisms in order to avoid it.
* **In Continuous based delivery,** congestion avoidance schemes that implement multipath routing are preferable, in order to avoid bottlenecks and reduce energy consumption.
* **Hybrid data delivery.** Nodes send their sensed data periodically to the sink, but when an event occurs or more information are demanded from the sink, nodes should send again their data. In this case hybrid algorithms that combine proactive and reactive mechanisms in order to avoid congestion are required.

1. Hierarchical routing protocols are based on clustering [↑](#footnote-ref-1)