GCCP-NS: Grid based Congestion Control Protocol with N-Sinks in a Wireless Sensor Network

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***Abstract*:** Wireless Sensor Networks (WSNs) have been a current trend in the research field and has many issues when there are multiple mobile sinks. Data dissemination gets critical as their locations have to be repeatedly updated and results in huge consumption of the restricted battery supply in sensor nodes. In this paper, we propose GCCP – NS, a grid based congestion control protocol with N -sinks that solves the data dissemination problem leading to congestion. We construct a dual level grid structure to trail the locations of all the source nodes that reports the information to the mobile sinks by monitoring the network in a hierarchical manner. As an added advantage, it aids in data dissemination based on query flooding from the mobile sinks using quorum based method within each cell in the grid and avoids congestion in an effective manner. Simulation results show that our proposed protocol outperforms the other schemes in terms of packet delivery ratio, energy expenditure and throughput.

***Keywords*:** Congestion, Data dissemination, Grid, Mobile sink, Wireless sensor networks.

1. Introduction

A WSN is self-possessed of a sensor field with a number of sensor nodes and sinks. These nodes sense the surrounding environment and report the information to the sinks through multi hop communication by performing some restricted computation with the limited battery supply. All the nodes have the role of a data router and an event detector. Wireless sensor networks have been ubiquitous in various applications like battlefield surveillance, habitat monitoring, health care monitoring, and environmental monitoring that includes flood warning, earthquake warning etc. An extensive range of dynamic information has to be reported frequently in such critical situations which is a challenging task in WSN. Many other challenges also arise based on the nature of the application, size of the network and the number of nodes and sinks.

One of the most critical issues in WSN is congestion control as when congestion arises near the sink, it becomes a hotspot and magnifies into an unacceptable level of packet loss. Due to this packets have to be retransmitted again which drains the limited battery supply which can lose the partial coverage of sensing area. In a densely deployed large scale sensor network, it becomes much critical to replace the low supply batteries and can possibly cause congested packets around the sink thereby decreasing the desired throughput. On transmitting and receiving packets, sensor nodes mostly lose their battery power leading to a congested network. This can be either node - level congestion due to buffer overflow or link - level congestion due to contention in the WSN. Many congestion detection mechanisms have been carried out based on packet loss, throughput, packet service time etc.

Early research works were carried out based on stationary sinks [1] which was aimed in prolonging the network life time and balancing the energy consumption. The existing mechanisms are not aimed in a congestion controlled as well as query driven network. Also when there are multiple mobile sinks, data has to be reported to the optimal sink without congestion and that is focused in our paper. In this paper, we propose GCCP–NS, a hierarchical methodology that considers the data dissemination mechanism with N – sinks that are mobile and has a congestion control framework. Throughout the sensor field, our proposed protocol constructs a dual level grid structure to trail all the locations of the source nodes rather than building the grid by each node. This is done by electing a node as a monitor node for queries from sinks on occurrence of any event. Each cell in the grid has the monitor node that does its job in a hierarchical manner. Thus our approach is both event and query driven and the early works were carried out separately and did not include both the mechanisms. Whenever a query pops up from the sink, the required data is disseminated using the quorum based method that sends the information about the source node i.e. the target to the mobile sink. Though the other nodes that are close to the sink are in the progressing path, they are not considered and only the node that has the shortest distance will be chosen which is based on the greedy geographical forwarding. The rest of the paper is organized as follows: Section 2 describes about the related work that were carried out earlier. Section 3 holds the details about the proposed protocol design. Section 4 has the performance analysis and we conclude the paper with Section 5.

2. Related Work

WSN is designed to be deployed based on the application requirements for various infrastructures. The work done by Mohammed et al [3] uses a Drop / Mark activation function and drops packets by comparing the predicted and allowed changes in the queue level. This gives an idea of whether packet dropping has to be made or not. Nazir et al. [4] proposed a mobile sink based routing mechanism (MSRP) in which the mobile sink gathers the sensed data from the cluster heads that have the highest energy around its neighborhood. Thus the hotspot problem is resolved with the sensor node that has the maximum energy near the sink and would not obviously drain fast. In [5] a new protocol named LO – PPAOMDV is proposed which combines the routing metrics link quality and MAC overhead and gives a normalized routing load and good packet delivery ratio. In Traffic Aware Dynamic Routing (TADR) [6] two hybrids a potential field are used to alleviate congestion by using the depth of node and queue length and clears the obstacles associated with congestion.

The work done by Li et al. [7] controls congestion for multiple class of traffic, schedules packets and detects congestion based on dual buffer threshold and weighted buffer difference. The congestion control mechanism in [8] is a priority based rate control mechanism which distinguishes between a real time high priority and low priority traffic. The real time traffic requires high reliability and low latency and the level of importance goes high when compared with non-real time traffic. Congestion Control and Fairness (CCF) [9] is a distributed algorithm which ensures fair delivery of packets within a sensor network and eliminates congestion. In this algorithm, the average rate of each node is calculated and that rate is divided among the child nodes to adjust the rate when queues are about to overflow. Thus congestion information is implicitly reported and the rate adjustment is exactly based on the available service rate.

Congestion Detection and Avoidance (CODA) [10] is energy efficient congestion control scheme for mitigating congestion that uses an open loop backpressure mechanism, a closed loop multi-source regulation scheme and a receiver based congestion detection. Channel utilization and buffer occupancy is monitored by each sensor node and queue length is used for detecting congestion. It also uses an AIMD rate adjustment and explicit congestion notification mechanism. Fusion [11] uses prioritized MAC with hop-by-hop flow control that has rate limiting to assuage congestion. Thus it achieves better fairness and increased throughput when compared to the other schemes. Interference-aware Fair Rate Control in Wireless Sensor Networks (IFRC) [12] uses multiple buffer thresholds for each node. When the buffer size of a node is about to exceed a predefined threshold level, it requests its neighbour to decrease the sending rate thereby ensuring fairness. Wan et. al [13] uses a reliable transport protocol namely Pump Slowly Fetch Quickly (PSFQ) which supports a scalable transport mechanism for meeting the needs of different data applications and provides reliability. Cross Layer Protocol (XLP) [14] achieves congestion control, MAC and routing in a cross layer manner. It ensures reliable communication by enabling the distributed duty cycle operation and receiver based contention.

Congestion Avoidance, Detection and Alleviation (CADA) [15] control congestion by using some representative nodes from the event area. Hotspots are also alleviated using the source rate regulation and dynamic traffic multiplexing. In [16], a Fairness Aware Congestion Control (FACC) [16] protocol categorizes nodes into near source nodes and near sink nodes. The near source nodes use a light weight packet dropping algorithm based on packet hit and buffer utilization. The Rate Controlled Reliable Transport (RCRT) [17] protocol gives control only to the sink for rate allocation and achieves flexibility and efficiency. In [18], buffer based congestion avoidance is implemented that solves hidden terminal problems inhibiting congestion. It uses multiple path routing and achieves near optimal throughput by using a 1/k buffer solution. Congestion Aware Routing (CAR) [19] identifies the congested areas that exists between sink and source data. It degrades the performance of low priority traffic and handles high priority data for congestion control based on MCAR. Feedback Congestion Control Protocol (FBCC) [20] uses a feedback scheme between the parent node and the children node and detects congestion using the queue length. The Lyapunov based approach is used to demonstrate the hop-by-hop congestion control and achieves high throughput and low energy consumption. Multiple Mobile Sinks Data Dissemination (MSDD) [23] monitors the network in a hierarchical manner by using a global agent to track the locations of all the sinks in cases of emergency and solves the data dissemination problem based the support of query driven data dissemination. Two – Tier Data Dissemination (TTDD) [24] approach provides scalable and efficient data delivery to multiple mobile sinks by constructing a grid structure and floods the queries within a local cell. It has better efficiency in handling mobile sinks when compared to the previous works and controls congestion with low overhead in the grid structure.

3. GCCP-NS: Protocol Design

3.1 Overview of the protocol

Many methods are adopted in a WSN with only a single sink and many source nodes to avoid the hotspot problem that is associated with congestion. The scenario gets worse when there are multiple sinks with each querying the required data and obtaining the information without collision at low energy expenditure is much critical. In this paper, we are focusing not only on multiple sinks but also on their mobility in the sensor network. The sensor network has a number of homogeneous sensor nodes which is divided into a cybernetic grid using Global Positioning System (GPS) or procedures such as [21]. The sensor nodes communicate with each other through radio signals and are aware of their location where the mobile sinks may or may not have knowledge of their own locations. The sensing area is partitioned into a grid structure and the sensor nodes are densely deployed with a number of source nodes and a number of sinks. After partitioning, each cell in the grid randomly elects a monitor node as the head for gathering the data to the sink. Thus flooding of control packets is avoided from all the nodes and decreases congestion around the sink.

There are two types of data packets to consider and they are (i) DBP - Data Broadcast Packet and (ii) DDP - Data Demand Packet. On occurrence of any event, the sensor node generates the data and forwards it to the monitor which is further advertised to the other monitors as DBP. Contrarily, when a sink needs some data, it sends a DDP to the adjacent monitor and gets the required data from the monitor node back to the sink. When DBP and DDP are sent to all the source nodes they can get collided with each other when no rule is adopted. To avoid congestion we use the use the concept of quorum so that data is demanded and broadcasted in an efficient manner. Consider a set P which has the subset of broadcast group G_b and demand group G_d. i.e. P = {G_b, G_d}. Each subset Y_b in G_b is called a data broadcast quorum and each subset Y_d in G_d is called a data demand quorum. Let us assume that G_b has j quorums and G_d has k quorums.

The following lemma should be adopted for quorums in group G_b and G_d under P.

Lemma 1: Property of Minimization

$$\forall Y_b, Z_b \in G_b :: Y_b \not\subset Z_b$$

$$\forall Y_d, Z_d \in G_d :: Y_d \not\subset Z_d$$

Lemma 2: Property of Intersection

$$(\forall Y_b \in G_b, \forall Y_d \in G_d :: Y_b \cap Y_d \neq \phi)$$

Lemma 3: Property of Union

$$\bigcup_{i=1} jY_{b_i} = P$$

$$\bigcup_{i=1} jkY_{d_i} = P$$

The cells are structured as DBP, DDP and are sent to quorums of cells through the broadcast group and demand group respectively in order to avoid overflowing of control packets. One particular cell in the grid receives both DBP and DDP together based on the lemma of intersection. Figure 1 represents the Grid based WSN. The circles represent the sensor nodes and the pink circles represent the monitor node. A yellow color master sink in is present in the central part which has an overall control over the network. We assume the battlefield surveillance system in Figure 1. There are three mobile sinks in the cells E1, G3 and H2 according to the scenario.

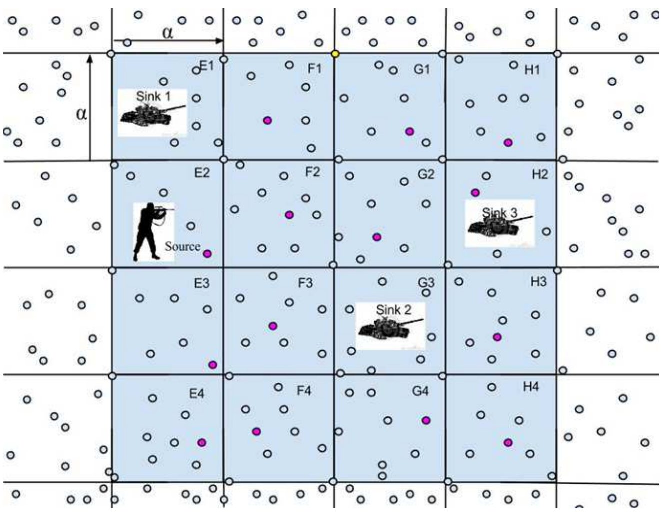

Figure 1. Grid based Wireless Sensor Network

Three mobile sinks represent three military tanks termed as sinks and are used to sense and report the gathered information to the master sink. A source node in E2 is a terrorist as per our example which has to be sensed by the mobile sinks. When an event occurs i.e. when a terrorist appears, the data is broadcasted via the monitor node through the data broadcast quorum using the greedy geographical forwarding mechanism [22]. The source node is identified in cell E2 and is broadcasted through the broadcast group via the cells {E1, E2, E3, and E4}. When the sink2 is moving around the cell for gathering information, it floods a query only to the nodes in the cell it resides and its monitor node spreads the DDP via the broadcast group quorum {E3, F3, G3, H3}. The monitor node of F3 receives both the DBP and DDP and sends the data to the sink. Thus congestion control is made by reducing the unnecessary control packets around the network and reduces the energy expenditure as packets are broadcasted and demanded only via the respective groups.

3.2 Grid structure

Each cell has a squared size area of α * α and on deployment of the sensing field, the cells are associated with the grid. The first cell in the grid is labelled as E1 with the first letter for representing the column and the numeric value for representing the row. There are three mobile sinks which are mainly used for collecting data and is involved in information services. There is a monitor node which is randomly elected among the sensor nodes. This is simply done by flooding the monitor broadcast message for a random amount of time. The node that responds to the message first will be elected as the monitor. As more energy is consumed by the monitor node, the neighbouring nodes are chosen as monitor after a certain time. This has to be carefully done before the chosen monitor drains out of battery. The reason is that, if a low powered node becomes the monitor, it loses its battery soon and has to lose the sensed data which would increase packet loss and increase the rate of congestion when gathering emergency data and can eventually become a hotspot.

The crossing points in the grid are called as dissemination points and for a source node at a location $S_l(a,b)$, the dissemination points $S_p(a_r,b_s)$ such that { $a_r = a+r\alpha$, $b_s=b+s\alpha$; r, s = ±0, ±1, ±2 }.The sink knows the dissemination points of its four neighbouring nodes by using the cell size α and the location (r, s). The greedy geographical forwarding is used for sending the DBP to S_p. Thus broadcast is made only to its adjacent node which reduces the chance of congestion in the entire cell. A master sink has the overall control of the entire grid. Once the grid is virtually built, it is not changed and whenever changes have to be made, it is done through three agents and they are Primary Agent Node (PAN) and Secondary Agent Node (SAN) and Global Agent Node (GAN). The location of monitor in each cell is collectively stored by PAN. When any cell tries to change the monitor node, the immediate neighbouring node gets the chance of being a monitor and this information is also updated in it. When the primary agent fails, the next option goes to the secondary agent SAN which periodically backs up all the information from PAN. All these activities are controlled by the GAN which periodically reports the modifications made in the network to the master sink. Thus congestion is avoided near the sink and hotspot problem is thereby solved.

3.3 Data broadcast

Each cell has a unique cell ID which stores the time when it generates the data along with the location information of the source node. This collective information is present in the DBP. When the monitor node receives the DBP, it broadcasts in both upward and downward direction so that all the cells' monitor nodes receive the advertisement throughout the grid. In this case, there is a chance of congestion as there are multiple intermediate nodes other than the monitor nodes. To resolve congestion, monitor nodes in each cell use a very limited number of intermediate nodes for data trajectory and stores the unique cell ID, time of data generation and location information during data broadcast. This in turn helps to reduce congestion as nodes will not have to collide during the second broadcast. Consider Figure 2 which represents the vertical way of data broadcast without flooding the broadcast in the entire network where DBP is sent through {E1, E2, E3, E4}.

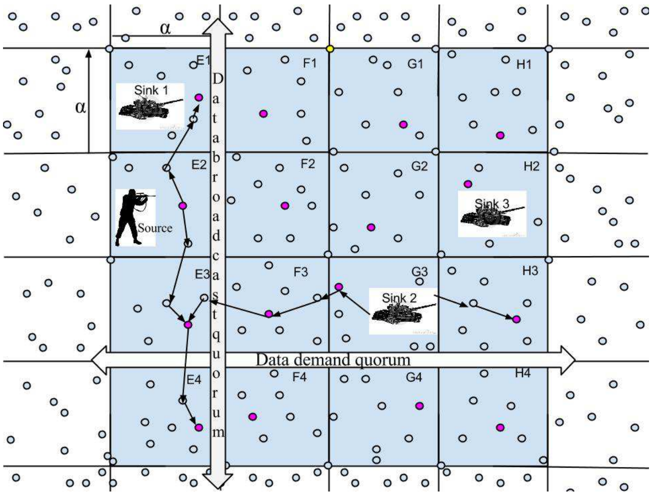

Figure 2. Trajectory of Data Broadcast and request via quorum

3.4 Data demand

The sink needs an instantaneous node and an instantaneous monitor node for demanding the data it needs. For electing the instantaneous node, the sink floods a beacon for a restricted number of hops and chooses the node which responds back with the highest signal to noise ratio. The monitor node of the elected instantaneous node becomes the instantaneous monitor of the sink. This is because the mobility of sink has to be known for the monitor node and updating is done without confusion. This is possible only when the sink moves within a certain distance and if it moves farther than the limit, a new instantaneous node has to be elected. All these are done under the supervision of the instantaneous monitor node.

When the sink demands the data, it sends a DRP to its instantaneous node which holds the unique cell ID and location information. This is further sent to the instantaneous monitor node through the data demand quorum and the cells {E4, F4, G4, H4}. Once DRP is received by the monitor node of E3, it forwards it to the monitor node of E2 in which the source node i.e. the target is present. Figure 2 shows the horizontal manner of data demand without flooding the information to all the surrounding nodes in the network.

3.5 Data forward

As discussed earlier, when a monitor node senses an event, it receives both the DBP and DRP as per quorum theory. It then checks the time of data generation whether it is stale or not. This is because as per the battlefield example, if the information has been generated hours or days ago, then that is of no use. If the monitor node finds that it is a newly generated data packet, it sends the information to the instantaneous monitor node which is forwarded to the instantaneous node and then to the sink. Figure 3 shows how the data trajectory of how data is forwarded from the cell that has the source node to the cell from which query was made from the sink.

3.6 Grid conversation

The communication overhead that is associated due to the nodes is discussed here. As each node should have the knowledge of the top stream and bottom stream nodes, the overhead for grid construction is 2 *rh where r is the number of sensor nodes and h is the length of each packet.

In order to maintain proper lifetime of the grid, a single node in each cell carries the lifetime of the grid which is generally based on the task of the sensor network and the available data. For example, if the tanks in Figure 1 do not move in collecting or sensing the target node i.e. source node, then there is no need of the grid. So in order to maintain this, the DBP holds the grid lifetime information. If the time becomes stale, then the grid cell no longer exists and is broadcasted to the other nodes through the data broadcast quorum. If the time exceeds than the original life time, then a new broadcast is made so as to give the information to the other nodes in the grid. At this point to avoid congestion, the grid should not be often refreshed and if it is done so, energy expenditure will be very high which can lead to failure of components in the grid.

The cost associated with data broadcast quorum and data request quorum together constitutes the cost for the re construction of the grid. We know that when the instantaneous node fails, a new node is elected by the instantaneous monitor node. But this update has to be made to the sink in a time out basis and when this happens, the sink floods the information again to obtain the sensed data. This same procedure is adopted on failure of PAN, SAN and GAN.

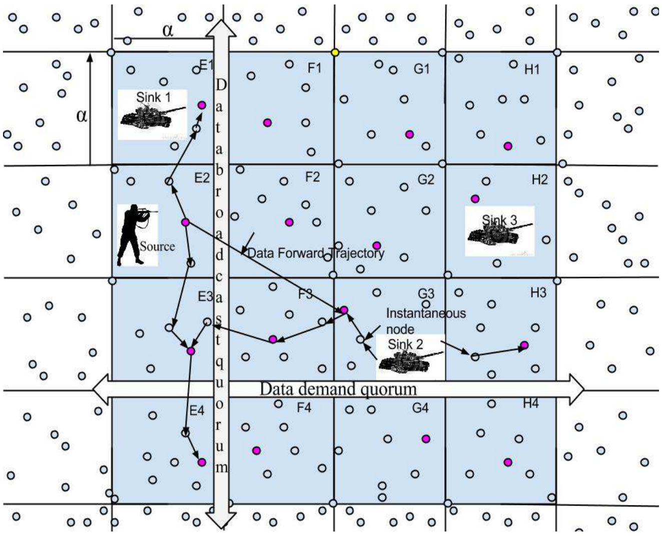

Figure 3. Data forward

4. Performance Evaluation

4.1 Simulation metrics

In this section we evaluate the performance of GCCP – NS via simulations using the NS-2 simulator. We use three metrics for evaluating the performance of GCCP – NS and they are throughput, energy expenditure and packet loss.

4.1.1 Throughput

It is defined as the ratio of the data generated by a source to the successful data collected at a sink calculated on an average of all source-sink pairs. This metric illustrates the effectiveness of data delivery.

4.1.2 Energy expenditure

It is defined as the amount of energy consumed on transmitting and receiving the data by the network excluding the idle energy spent because we have more importance only on data generation.

4.1.3 Packet loss

It is the total number of packets lost or dropped by the nodes before the sensed data reaches the sink which can be due to signal deprivation, network deterrence etc. It is a very important metric because once packets are lost, they have to be retransmitted again with double the times of battery loss.

4.2 Simulation setup

The number of mobile sinks range from 3 to 5 with a total of 200 sensor nodes, 3 source nodes densely deployed over a 2000 * 2000 m^2 area with a radio range of 100 *m*. We use the 802.11 MAC protocol with the beacon or pause interval set to 5 *seconds* and the initial sink speed is set to 10 *m/s*. The size of each packet is 64 *bytes*, transmitted at 0.6 *W* power consumption and received at 0.35 *W*. Each simulation extends up to 300 *seconds*.

Table 1. Simulation parameters

Parameter	Value
MAC Protocol	802.11
No of mobile sinks	3 to 6
No of source nodes	3
No of sensor nodes	200
Nature of traffic	Variable
Radio Range	100 m
Simulation time	300s
Transmitting Power consumption	0.6 W
Receiving Power Consumption	0.35 W
Simulation Area`	2000 * 2000 m^2
Initial Sink Speed	10 m/s
Beacon Interval	5 seconds
Size of data packet	64 bytes
Simulation Time	300 seconds

4.3 Comparative analysis

We compare the performance of our proposed protocol GCCP- NS with the other schemes TTDD [23] and MSDD [24].

4.3.1 Throughput comparison

We compare the throughput with respect to the sink speed and source node failure. The number of sinks varies from 3 to 6 and the speed is set to 10 m/s. The successful number of packets delivered fluctuates when the sink speed changes. Figure 4 represents the throughput with an increase in sink speed and we understand that GCCP – NS has an 80 % success rate from 8 to 12 sink speed and falls down afterwards. MSDD also peaks in the same condition whereas the stabilized success rate ranges just between 60 to 65 % and has an unstable success rate from 55 to 60 % for TTDD. This proves that grid based WSN achieves much better throughput than the existing mechanisms.

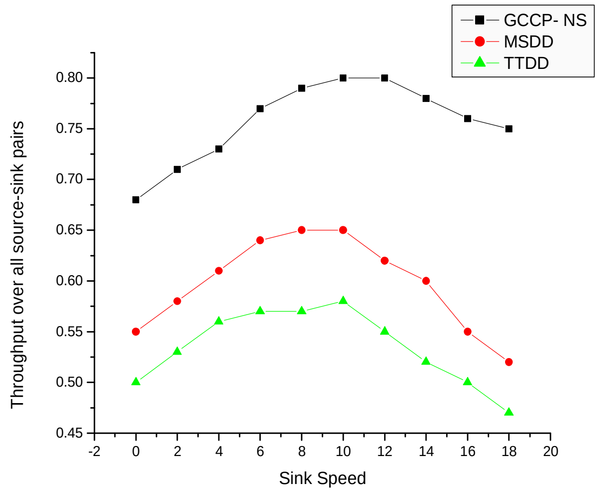

Figure 4. Throughput versus sink speed

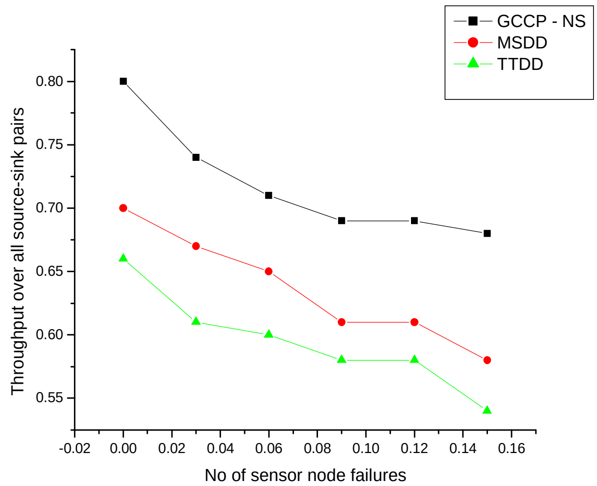

Figure 5. Throughput with respect to sensor node failures

Figure 5 shows the throughput with respect to sensor node failures in which our proposed protocol falls down below 68% when 3 to 16 % of the sensor nodes fail. This failure may be due to discrepancies in the network, very poor signal to noise ratio or unstable channel allocation. MSDD slopes down to 58 % and TTDD to 52 % assuring that the network cannot be relied in successful transmitting and receiving packets and the condition gets worse for event based applications.

4.3.2 Energy expenditure comparison

We make two observations for energy expenditure. Figure 6 represents the energy expenditure with respect to the sink speed. As the number of sinks increase, the curve of GCCP – NS increases gradually in a sub linear way reaching 1250 Kbps. The reason is that, each sink needs data and queries according to its own requirement and more nodes are utilized for gathering the data. The cumulative data are sent to the instantaneous monitor, instantaneous node and then to the sink after sending DBP and DRP through the respective quorums. As congestion have to be avoided, when the above procedure is adopted, it obviously consumes more energy.

But it is less when compared to MSDD and TTDD which are very high more than 1200 Kbps which is the maximum energy consumed by our protocol.

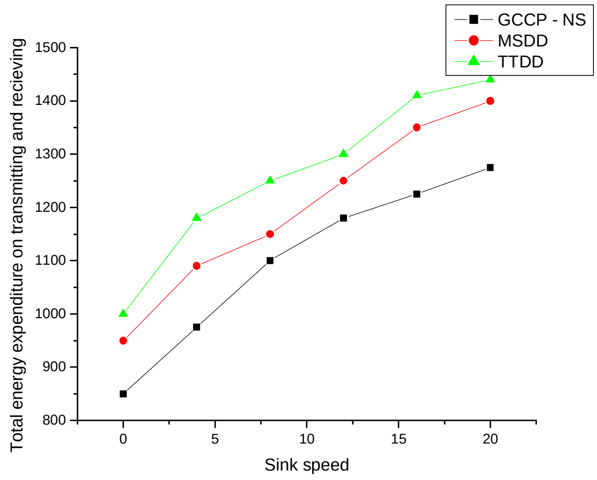

Figure 6. Energy expenditure with respect to Sink speed

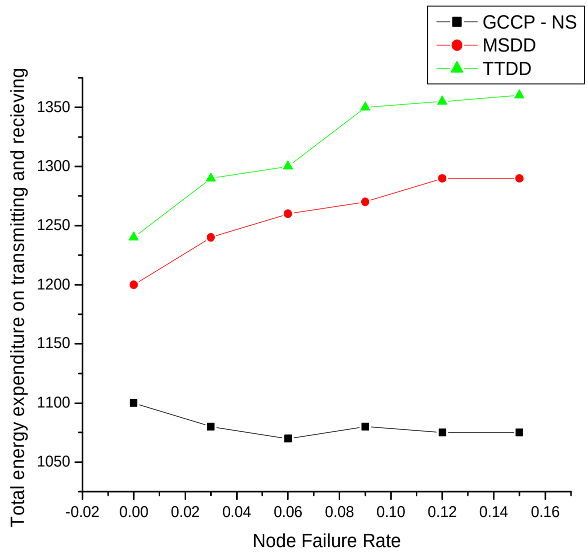

Figure 7. Energy expenditure with respect to Node failure rate

From Figure 7, we observe the energy expenditure with respect to the node failure rate. Generally, more energy is consumed when node failure rate is high as data transmitting and receiving has to be made again and leads to congestion due to loss of packets. GCCP – NS slopes up and down from 6% to 16% and is considerably low when compared with MSDD and TTDD that grows exponentially high.

4.3.3 Packet loss comparison

In the simulation setting, the sink speed is 10 *m/s* and we increase it up to 20 *m/s*. As the sink speed is increased, there may be packet loss while transmitting or receiving the data and may cause congestion when the cumulative data is sent to the sink. Figure 8 represents the packet loss with respect to the sink speed in which GCCP – NS loses just less than 220 packets whereas MSDD and TTDD loses 300, 400 packets lost respectively. This can get worse when the sink speed is further increased.

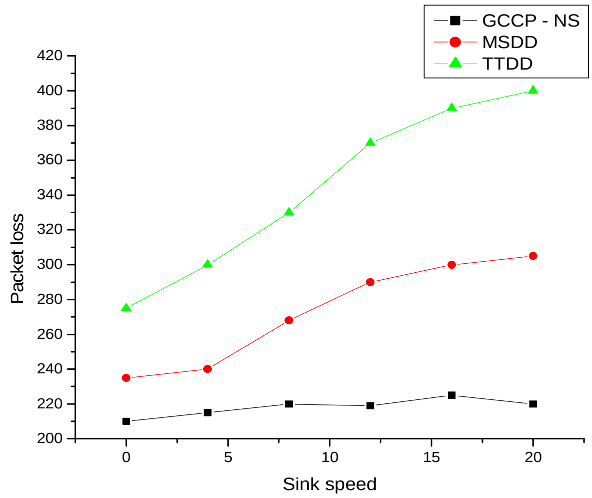

Figure 8. Packet loss with respect to number of sinks

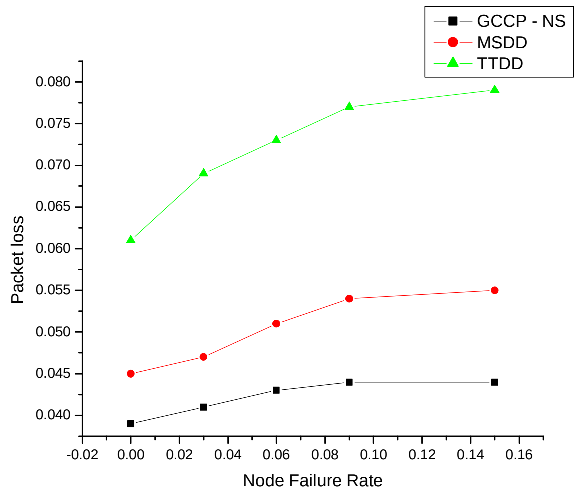

Figure 9. Packet loss with respect to Node failure rate

5. Conclusion

In this paper we propose GCCP – NS, a grid based congestion control protocol with N sinks to empower successful data dissemination by constructing a dual level grid to trail the locations of all the source nodes based on the queries from the mobile sinks using the concept of quorum to avoid congestion. Since data is transmitted and received only based on the queries within a particular cell in a grid, the problem of flooding is resolved. Our simulations have confirmed the efficiency and effectiveness of the proposed protocol, signifying the likelihood of constructing the infrastructure in stationary WSNs. Our future work can be extended to use the grid structure for health care applications so that the principle of mobile sinks will be much helpful in aiding the humans.

References

[1] C. Sergiou, P. Antoniou, V. Vassiliou, “A comprehensive survey of congestion control protocols in wireless sensor networks,” IEEE Communication Surveys and Tutorials, Vol. 16, No. 4, pp. 1839 – 1859, 2014.

[2] Liaojun Pang, Huixian Li, Qingqi Pei, Guozhen Xiao, “Fair Data Collection Scheme in Wireless Sensor Networks”, China Communications, Vol.10, No. 2, 2013.

[3] Mohammed M. Kadhum, Suhaidi Hassan, “The Drop Activation Function of the Fast Congestion Notification (FN) Mechanism”, International Journal of Computer Networks and Information Security, Vol. 1, No. 3, pp. 46 – 51, 2009.

[4] B. Nazir, H. Hasbullah, “Mobile Sink based Routing Mechanism (MSRP) for Prolonging Network Lifetime in Clustered Wireless Sensor Network”, IEEE International Conference on ICCAIE, pp. 624 – 629, 2010.

[5] Moussa Ali Cherif, Mohamed Kamel Feraoun, Sofiane Boukli Hacene, “Link Quality and MAC- Overhead aware Predictive Preemptive Multipath routing protocol for Mobile Ad hoc Networks,” International Journal of Computer Networks and Information Security, Vol. 5, No. 3, pp. 210 – 218, 2013.

[6] Fengyuan Ren, Tao He, Sajal K. Das, Chuang Lin, "Traffic-Aware Dynamic Routing to Alleviate Congestion in Wireless Sensor Networks", IEEE Transactions on Parallel & Distributed Systems, Vol. 22, No. 9, pp. 1585 – 1599, 2011.

[7] C. Sergiou, V. Vassiliou, “Energy hole prevention in wireless sensor networks”, Proceedings of the 9th ACM/IEEE International Conference on Information Processing in Sensor Networks (Poster session), New York, USA, pp. 398 – 399, 2010.

[8] C. G. Wang, B. Li, K. Sohraby, “Upstream congestion control in wireless sensor networks through cross-layer optimization”, IEEE Journal on Selected Areas in Communications, Vol. 25, No. 4, pp. 786 – 795, 2007.

[9] C. T. Ee, R. Bajcsy, “Congestion control and fairness for many-to-one routing in sensor networks”, Proceedings of ACM Conference on Sensor systems, pp. 148 – 161, 2004.

[10] C. Y. Wan, S. B. Eisenman, A. T. Campbell, “CODA: Congestion detection and avoidance in sensor networks”, Proceedings of 1st ACM Conference on Embedded Networked Sensor systems, pp. 266 – 279, 2003.

[11] B. Hull, K. Jamieson, H. Balakrishnan, “Mitigating congestion in wireless sensor networks”, Proceedings of 2nd ACM Conference on Embedded Networked Sensor systems, pp. 134 – 147, 2004.

[12] S. Rangwala, R. Gummadi, R. Govindan, K. Psounis, “Interference-aware fair rate control in wireless sensor networks”, Proceedings of SIGCOMM, pp. 63 – 74, 2006.

[13] C. Y. Wan, A.T. Campbell, L. Krishnamurthy, “PSFQ: A reliable transport protocol for wireless sensor networks”, Proceedings of ACM Conference on Wireless Sensor Networks and Applications, pp. 1 – 11, 2002.

[14] C. Vuran Mehmet, I. F. Akyildiz, “XLP: A Cross- Layer Protocol for efficient communication in Wireless Sensor Networks”, IEEE Transactions on Mobile Computing, Vol. 9, No. 11, pp. 1578 – 1591, 2010.

[15] Wei Wei Fang, Ji ming Chen, Lei Shu, Tian shu Chu, De pie Qian, "Congestion avoidance, detection and alleviation in wireless sensor networks" Journal of Zhejiang University-Science, Vol. 11, Issue. 1, pp. 63 – 73, 2010.

[16] X. Yin, X. Zhou, R. Huang, Y. Fang, “A Fairness-Aware Congestion Control Scheme in Wireless Sensor Networks”, IEEE Transactions on Vehicular Technology, Vol. 58, No. 9, 2009.

[17] J. Paek, R. Govindan, “RCRT: Rate-controlled reliable transport for wireless sensor networks”, Proceedings of 5th ACM Conference on Embedded Networked Sensor systems, pp. 305 – 319, 2007.

[18] S. Chen, N. Yang, “Congestion avoidance based on lightweight buffer management in sensor networks”, IEEE Transactions on Parallel and Distributed Systems, Vol. 17, No. 9, pp. 934–946, 2006.

[19] R. Kumar, R. Crepaldi, H. Rowaihy, Gohong Cao, A. F. Harris, “Mitigating Performance Degradation in Congested Sensor Networks”, IEEE Transactions on Mobile Computing, Vol. 7, Issue. 6, pp. 682 – 697, 2008.

[20] M. Li, Y. Jing, “Feedback Congestion Control Protocol for Wireless Sensor Networks”, 24th Chinese Control and Decision Conference (CCDC), pp. 4217 – 4220, 2012.

[21] Joe Albowicz, Alvin Chen, Lixia Zhang, “Recursive Position Estimation in Sensor Networks”, 9th IEEE International Conference on Network protocols (ICNP), pp. 35 – 41, 2001.

[22] Brad Karp, H. T. Kung, “GPSR: Greedy perimeter Stateless Routing for Wireless Networks”, ACM International Conference on Mobile Computing and Networking, pp. 243 – 254, 2000.

[23] Xie Dongliang, Wu Xiaojie, Li Dan, Sun Jia, “Multiple Mobile Sinks Data Dissemination Mechanism for Large Scale Wireless Sensor Networks”, China Communications, Vol. 11, No. 13, pp. 1 – 8, 2014.

[24] Fan Ye, Haiyun Leo, Jerry Cheng, Songwu Lu, Lixia Zhang, “TTDD: A two – tier data dissemination model for large-scale wireless sensor networks”, ACM International Conference on Mobile Computing and Networking, pp. 148 – 159, 2002.