Diverse Congestion Control Schemes for Wireless Sensor Networks

1* Amit Grover, 2 Anu Sheetal, 3 Vishal Sharma, 4 Chakshu Goel, 5, 6 Mehtab Singh, 7, 8 Meet Kumari
1, 3, 4 Department of Electronics and Communication Engineering, Shaheed Bhagat Singh State University, Ferozepur, India
2 Department of Engineering and Technology, Guru Nanak Dev University, Regional Campus, Gurdaspur, India
3 Department of Electronics and Communication Engineering, Satyam Institute of Engineering and Technology (IKG-PTU, Kapurthala), Amritsar, India
4 Department of Engineering and Technology, Guru Nanak Dev University, Regional Campus, Jalandhar, India
5 Department of Electronics and Communication Engineering, Punjabi University, Patiala, India
6 Department of Engineering and Communication Engineering, Chandigarh University, Mohali, India
* Corresponding Author E-mail: amitgrover321@gmail.com

Article History: Received: 10 November 2020; Revised 12 January 2021 Accepted: 27 January 2021; Published online: 5 April 2021

Abstract: Wireless Sensor Networks (WSNs) comprised of battery operated sensor nodes that collect data from their neighbor nodes and transmit the aggregated information to the sink node or the Base Station (BS). This may result in congestion near the BS and leads to a bottleneck situation in the network. In this paper, an extensive study of earlier reported diverse congestion techniques explicitly diverse Algorithm based - and Layer based-congestion techniques is carried out. Accordingly, a recommendation is drawn based upon their performance comparison. Furthermore, a demonstration is carried out for contemporary earlier reported strategies such as Pro-AODV, CC-AODV, EDAPR, ED-AODV and PCC-AODV by evaluating delay, packet delivery ratio (PDR) and packet loss ratio (PLR). Accordingly, a recommended congestion strategy is suggested depending upon the comparison of the demonstrated schemes.

Keywords: Wireless Sensor Networks, Congestion, Congestion controlled strategies

1. Introduction

Wireless Sensor Networks (WSNs) consist of a large number of geographically distributed, battery-operated sensor nodes with some processing capabilities to collect process and transfer data to the BS but are limited to restore the dead nodes due to depletion of the battery and to extend the system/network life-span. To accomplish the primary objective of data sensing and collection of wireless sensor networks, the design of an energy efficient routing algorithm is very important. The numerous hierarchical routing protocols like TEEN, APTEEN, and PEGASIS are developed and extended from conventional strategies [1]. Further, an improved Distributed, Multi-hop, Adaptive, Tree-based Energy-Balanced (DMATEB) routing scheme is demonstrated in which a relay node is selected in view of minimum distance and high energy from a current sensing node [2]. Further, the parent node is chosen among the selected relay nodes on the basis of high residual energy and less power consumption with due consideration of its associated child nodes. As each sensing node itself selects its parent among the available alternatives, the proposed scheme offers a distributive and adaptive approach. Moreover, the reported system proffers marginal overload to a specific selected parent node. The selected parent-node further starts acting as a child-node whenever its energy gets fewer than the accessible relay-nodes. Furthermore, the optimization techniques [3-9] come out as a promising candidate to combat with this issue effectively. An inter-cluster and intra-cluster communication is demonstrated by proposing an ACO optimized Self-Organized Tree-Based (AOSTEB) Energy Balance strategy to discover an efficient route within a specific cluster on account of the shortest distance and less energy [10]. An efficient and scalable ZigBee based WSN network is also demonstrated recently to accommodate the topology-fluctuations, node-mobility/density/ and network-size at optimum node-mobility [11] and recommend the cluster-tree topology to proffer the optimum QoS services.

Addition to the prolonging of network lifespan by means of diverse energy efficient routing techniques, the implementation of such networks are also experience another limiting issue of congestion that comes into play...
due to the simultaneous transmission attempts executed by different sensor nodes. Congestion results in data loss and degrades the performance of a network by decreasing the throughput. Depending upon the impact of congestion, it is classified into two categories namely: local congestion and global congestion. Congestion at the local level mainly occurs either due to the node or link failure. However, global congestion occurs in the whole network and hence, minimizes the data transfer rate. In WSNs global congestion rarely occurs due to availability of the sufficient resources. However, the local congestion occurs more often due to the limited battery life and memory availability of deployed sensor nodes. Local congestion can occur either due to node failure or buffer overflow. Buffer overflow occurs if several nodes try to transmit data packets simultaneously to the single destination sensor node. This work investigates the earlier reported congestion techniques and has been classified into two categories namely Algorithm based Congestion Techniques and Layer based Congestion Techniques. The remaining of the paper is organized as follows: Section 2 highlights the diverse congestion control techniques and Section 3 presents the simulation results of presently available congestion control techniques and conclusion is drawn based upon the comparative analysis of diverse congestion control techniques and mentioned in section 4.

2. Diverse Congestion Control Strategies

In the layer based congestion technique, each sensor node senses the channel for a fixed amount of time before transmitting its own data. This waiting time leads to significant performance degradation and can be reduced by introducing random sensing times instead of a fixed waiting time with usage of sequential detectors. This will also minimize the average number of samples required to make a decision for transmission of data onto the channel and hence leading to reduction in the communication delay, power consumption and the risk of collisions [12]. Neural Network based congestion detection (NNBCD) a layer based congestion protocol has been proposed to detect the level of congestion during the significant packet drop in the network by considering the buffer occupancy and traffic rate [13]. Further, a Delay-aware congestion control (DACC) protocol estimates channel occupancy based on buffer occupancy and transmission time of packets. REDD (Real-time and Energy-aware Directed Diffusion) routing protocol improves the performance of DACC protocol by reducing the estimation time and improves the network efficiency [14]. Further, an intelligent collision avoidance mechanism is proposed for the vehicular ad hoc network that uses ultrasonic sensors and IR sensors for front barrier detection and controls the flooding effect occurring due to duplicate message transmission [15]. Energy based collision avoidance (ECA-MAC) technique handles WSN energy constraints and the QoS designed for versatile applications [16]. Based on different energy levels of nodes, ECA-MAC protocol controls the access to the channel and reduces the collision using different contention windows and hence improves the lifetime of the network. Modified Opportunistic Routing Protocol (MORR) improves the data routing in WSNs by allowing only the sensor nodes that have higher residual energy and minimum neighbor nodes to transmit the data packets to reduce the congestion in the network [17]. Table 1 shows the comparison of the layer based congestion control mechanisms for collision detection.

| Table 1. Comparison of Layer based congestion control mechanisms for collision detection |
|------------------------------------------------|
| Name of mechanism | Layer on which it works | Reason of congestion | Improves | Designed For |
|-------------------|--------------------------|----------------------|----------|--------------|
| Sequential Detection [12] | Physical Layer | Not Defined | Transmission Delay | WSN |
| Neural Network based Congestion Detection [13] | Transport Layer | Number of Participants, Buffer Occupancy and Traffic Rate | Packet drop rate | WSN |
| Delay Aware Congestion Control [14] | MAC Layer | Workload Exceeds than Available Communication Capacity | Delay | WSN |
| Ultrasonic and IR Sensors [15] | MAC Layer | Several Reasons | Power Consumption and Design Cost | Vehicular Network |
| Energy-Based Collision Avoidance [16] | MAC Layer | Contention Window | Energy Consumption | WSN |
Congestion control for MUlti-class Traffic (COMUT), a cluster-based mechanism supports multiple classes of traffic for sensor networks [18]. COMUT organizes the whole network into small, independent parts, and each part looks for congestion within its localized scope. This result in abating congestion and reducing the wasteful packet drops to save energy; however, COMUT fails to estimate the network traffic intensity. Congestion control for Sink to Sensors (CONSISE) is based upon co-activities like receiving, transmitting, transmit-decision and receive-decision [19]. This slows down the communication as the quantity of sensor nodes and the generated data traffic increases. To overcome this problem and to achieve high throughput, an adaptive duty-cycle based congestion control (ADCC) scheme had been proposed [20] that control both resource and traffic inside the network. The ADCC scheme reduces the control packet overhead by increasing and reducing the packet reception-transmission- rate of the receiving/sending node respectively. Further, the ADCC scheme, a light weight congestion control the energy efficient scheme uses the duty-cycle adjustment but is not appropriate for Many-to-one sensor networks. Thus, two distributed algorithms had been proposed to efficiently find an alternative path using the neighboring table and mitigating the congestion by using an idle path instead of restricting transmit rate [21].

To improve the network lifetime, an On-demand node placement strategy reacts to congestion regions and transmits the traffic to non-congestion regions [22]. However, buffer overflow results in high packet loss and a large queuing delay that further augments the packet service-time and energy wastage. An early congestion detection and an adaptive routing (EDAPR) overcomes this drawback [23] by constructing non-congested-neighbors (NHN) list and discovers the path from the source node to the destination node using NHN node. Each sensor node detects the congestion occurrence or its probability and sends a warning message to NHN sensor nodes to discover an alternative path to reach to the destination node. This improves network lifetime but at the cost of high packet loss and prolonged delay [24]. Further, an optimized fuzzy logic based congestion control mechanism improves the performance of the network that considers buffer occupancy and congestion index (CI) and estimates the congestion occurrence but at the cost of increased network load [25]. A cross-layer congestion control (CLCC) strategy overcomes this limitation by considering rate adjustment for controlling the congestion and application-oriented design for the different situations but at the cost of long delay [26-33]. Further, an adaptive congestion control protocol (ACCP) improves the network performance by using a sink switching algorithm to switch between traffic congestion control logic (DelStatic) and resource congestion control logic (DSR) [34]. The packet loss or drop rate can be minimized by adopting a priority based congestion detection and the avoidance scheme. This strategy differentiated data delivery during congestion which includes the packet priority assignment, priority based queue scheduler and dynamic dual-path congestion algorithm [35].

**Table 2.** Comparison of various algorithm based congestion control mechanisms

| Name of mechanism | Way to notify congestion | Reason of congestion | Energy conservation |
|-------------------|--------------------------|----------------------|---------------------|
| Cluster Based Congestion control [18] | Sentinel network | Traffic Intensity | Good |
| Feedback Congestion Control [19] | Feedback | More loads on channels | Good |
| Adaptive duty-cycle based congestion control [20] | Based on calculated service time | Due to increase in number of nodes when network grows | Good |
| Alternative Path Search mechanism [21] | • Set value of F(t)=0<br>• Buffer Queue’s value | Due to node failure and Aggregate Flow of data | Not defined |
| On-demand Node Placement Algorithm [22] | Expected Transmission Delay and Drop Packet Count | Node Density Level | Not defined |
| Early Congestion Detection And Adaptive | Queue status at node level. | High Packet Loss and Long Delay | Not defined |
| Scheme                                                                 | Criteria                                                                 | Quality |
|-----------------------------------------------------------------------|--------------------------------------------------------------------------|---------|
| Diverse Congestion Control Schemes for Wireless Sensor Networks       |                                                                         |         |
| Routing [23]                                                          | Predictive Congestion Control Mechanism [24]                             |         |
|                                                                       | Bidirectional Route Finding                                              |         |
|                                                                       | High Packet Loss and Long Delay                                          |         |
|                                                                       | Buffer occupancy                                                        |         |
|                                                                       | Increase in network load                                                 |         |
| Cross-layer Congestion Control [26]                                    | Multipath Routing                                                       |         |
|                                                                       | Packet dropout and long delay                                            |         |
| Adaptive Congestion Control Protocol [34]                              | Buffer Occupancy and Channel Utilization                                 | Good    |
|                                                                       | Bandwidth Exceeds the threshold                                          |         |
| Priority Based Congestion Detection and Avoidance [35]                 | Dynamic Congestion Aware Routing                                         |         |
|                                                                       | Packet dropping                                                         |         |
| Cross-layer Congestion Control based on Compressed Sensing [36]        | Compression of transmitted Signal and Allocated Channel                  | Good    |
|                                                                       | Several Signals seize the same channel                                  |         |
| Feedback Congestion Control [37]                                       | Feedback                                                                | Good    |
|                                                                       | Buffer Overflow                                                         |         |
| Proactive AODV [38]                                                    | Routing Table                                                           |         |
|                                                                       | Route Request                                                           | Not defined |
| Cross-layer Admission Control [39]                                     | Avoiding useless packets                                                | Good    |
|                                                                       | Delay and Packet Loss                                                   |         |
| Congestion Control AODV [40]                                           | Received signal strength                                                |         |
|                                                                       | Transmission Power and distance between nodes                           | Not defined |
| Traffic Redirection based Congestion Control Transport Protocol [41]   | Traffic Redirection                                                     | Good    |
|                                                                       | Buffer Overflow                                                         |         |
| Congestion Detection and Alleviation [44]                              | Rerouting of Traffic                                                    | Good    |
|                                                                       | Buffer Overflow                                                         |         |
| Congestion Control and Energy Balanced Scheme [46]                    | Queue Length, Forwarding and receiving rate                             | Good    |
|                                                                       | Buffer Overflow                                                         |         |
| Congestion Control Adaptive Routing [49]                               | Acknowledgement                                                         | Not defined |
|                                                                       | Traffic Intensity                                                       |         |
| Initial Constant Congestion Window [50]                                | Acknowledgement                                                         | Excellent|
|                                                                       | Bottleneck Link                                                         |         |
Apart from this, still there are chances of the packet dropping that can be overcome by cross-layer congestion Control algorithm applicable at both node-level and link-level. This improves the network lifetime by compressing the transmission signal and allocated the channel that makes high levels of data flow but at the cost of seizing the same channel while maintaining a high level of data flow [36]. This can be overcome by using feedback congestion control which is based on linear discrete time control concept that improves the system performance in terms of energy consumption and high throughput, but is affected by buffer overflow issues that causes significant drop in packets [37]. A pro-active protocol uses information from the AODV routing table to minimize this packet drop rate and congestion. The drawback of this technique is whenever a node decides to broadcast a route request (RREQ); it only chooses a subset of nodes listed in the table [38]. To overcome this, a cross-layer admission control (CLAC) mechanism is reported which is based on technique that preview packet end-to-end delay and forward the same if expected to meet end-to-end delay, otherwise dropped the packets. This enhances the performance in terms energy efficiency but at the cost of high packet loss [39]. This further is a combat with a congestion control AODV algorithm that is used to avoid link break and in which the received signal strength was being used as cross layer design parameter. The only drawback of this algorithm is drop of packets whenever the required transmission power and the distance between the nodes increase [40]. Traffic redirection based congestion control transport protocol (TRCCTP) is reported which is based on finding the optimal path that redirects the traffic from congested area to uncongested area and minimizes the packet drop ratio [41-43]. Another technique named congestion detection and alleviation (CDA) mechanism is reported which is based on carrier sense multiple access with collision avoidance (CSMA/CA) in which node level congestion and link level congestion is detected by buffer utilization and congestion is alleviated by rerouting the traffic to a less congested route, which minimizes the packet drop ratio [44]. Another approach known as congestion avoidance and congestion control mechanism was proposed to overcome the problem of packet dropping. In congestion avoidance, the node uses the lower hierarchy nodes to forward the data and congestion control mechanism will detect the congestion using queue length. The only drawback of this approach is buffer overflow [45-46]. Congestion control [47-48] adaptive routing overcomes the problem of buffer overflow. In this congestion detection, alternate path computation and rerouting of packets are being carried out based on free space available in the buffer, available bandwidth, hop distance and residual energy on the path [49]. Another proposed algorithm is initial constant congestion window that calculates the values of threshold on the basis of acknowledgements, that improves the lifetime of sensor nodes by introducing a novel mobile node as a charger and handles the congestion of bottleneck links by using initial constant congestion window (ICCW) [50]. Table 2 shows the comparison of various Algorithm based congestion control mechanisms.

3. Simulation Results of Congestion Control Strategies

Furthermore, the performance of different algorithm based congestion techniques via different metrics; for instance, packet delivery ratio (PDR), packet loss ratio (PLR), Throughput and delay at different node density are computed.

Table 3 shows the comparison of existing congestion control strategies like PRO-AODV (Proactive), CC-AODV (Congestion control), EDAPR (Early congestion detection and adaptive routing), PCC-AODV (Predictive congestion control routing) and ED-AODV (Early congestion detection control routing) in terms of number of flows.

| Number of flows | PRO PDR | ED PDR | PCC PDR | ED PDR | PRO Throughput | ED Throughput |
|-----------------|---------|-------|---------|-------|----------------|--------------|
| 10              | 0.5     | 0.6   | 0.2     | 0.16  | 94.2           | 76.2         |
| 20              | 0.8     | 2.4   | 0.4     | 0.33  | 92.8           | 82.8         |
| 30              | 1.9     | 4.9   | 1.4     | 0.56  | 90.5           | 88.3         |

Figure 1-3 shows the comparison of End to end delay, packet delivery ratio (PDR) and Throughput for ProAODV [38], CC-AODV [40], EDAPR (Early congestion detection control routing) [23], ED-AODV (Early congestion detection control routing) [23] and PCC-AODV (Predictive congestion control routing) [24] protocols respectively. Fig 1 clearly describes that PCC-AODV outperforms the other algorithms in terms of delay (0.16 at 10 number of flows) while average delay increases with increase in number of flows.
Fig 2 describes the performance of PRO-AODV as the best one in case of packet delivery ratio (90.5 at maximum number of flows), as this is able to look for routes towards the destinations by avoiding congestion in large network size which contributes toward higher delivery by reducing packet drop ratio. Fig 3 demonstrates PRO-AODV as the best strategy in terms of throughput (189 at 30 numbers of flows) while ED-AODV performs better at least number of flows because it has lesser number of connections at this level and is able to find the route easily while increase in number of flows increases the number of active connections that initiates more route searches which in turn decrease the throughput of ED-AODV.

Table 4 shows the comparison of different congestion control strategies with varying number of nodes for PRO-AODV (Proactive), CC-AODV (Congestion control), EDAPR (Early congestion detection and adaptive
routing), PCC-AODV (Predictive congestion control routing) and ED-AODV (Early congestion detection control routing) in terms of Packet delivery ratio (PDR), Packet loss ratio (PLR) and Throughput.

Table 4. Comparison of Different Congestion Control strategies in terms of number of nodes

| Number of flows | PR O | CC | ED AR | PCC | ED | PR O | CC | ED AR | PC C | ED | PR O | CC | ED AR | PC C | ED |
|----------------|------|----|-------|-----|----|------|----|-------|------|----|------|----|-------|------|----|
| 50             | 94.7 | 100| 94    | 95.5| 99.7| 5.3  | 0  | 2.3   | 5.4  | 1.2| 232  | 233| 198   | 195 | 199 |
| 75             | 93.8 | 97 | 95.2  | 96.2| 95.5| 6.1  | 4.4| 5.5   | 4.5  | 2.4| 192  | 195| 191   | 192 | 194 |
| 100            | 94.7 | 98.9| 97.3  | 97.5| 94.5| 5.3  | 1.1| 5.2   | 2.4  | 3.3| 196  | 198| 192   | 191 | 192 |
| 125            | 95.2 | 97.8| 97.5  | 99.2| 94.4| 4.7  | 2.2| 4.8   | 1.5  | 5.4| 195  | 197| 191   | 189 | 191 |
| 150            | 93.8 | 97.8| 98.1  | 100 | 92.5| 6.1  | 2.2| 3.2   | 1.0  | 6.1| 194  | 197| 179   | 188 | 190 |

Figure 4-6 shows the comparison of Packet delivery ratio (PDR), Packet loss ratio (PLR) and Throughput for Pro-AODV [38], CC-AODV [40], EDAPR (Early congestion detection and adaptive routing) [23], ED-AODV (Early congestion detection control routing) [23] and PCC-AODV (Predictive congestion control routing) [24] protocols respectively. From Fig 4 and Fig 5, it has been demonstrated that PCC-AODV outperforms in terms of packet delivery ratio, as with increase in number of nodes, routes are efficiently managed in this mechanism and so does the packet loss ratio which depends upon PDR because routes are being managed using optimum route maintenance policy in this mechanism. Fig 6 describes the CC-AODV outperforms than other mechanisms in terms of throughput (233 at 50 number of nodes) because it aims to reduce performance degradation that occurred due to congestion.

Figure 4. PDR evaluation at varied number of nodes

Figure 5. PLR evaluation at varied number of nodes
The outcomes of the demonstrated diverse congestion techniques show that PCC-AODV outperforms the other algorithms in terms of PDR and PLR. Further, it has been observed that ED-AODV claims a decreased approach in dense traffic rate.

4. Conclusions

Controlling congestion is a demanding and complex issue in the WSN networks having limited resources. The numerous strategies have been discussed previously to manage congestion to expand the network lifetime by using restricted available resources adequately. Researchers have categorized these schemes mainly into algorithm- and layer-based congestion control algorithms. This article examines earlier reported Algorithm- and Layer-based strategies, present a comparative and discussed their pro and cons accordingly. This may help the researchers to opt for an appropriate congestion strategy as per network design and required QoS services. Furthermore, the authors assessed current existing congestion control techniques in terms of delay, throughput, PDR and PLR and claimed PCC-AODV as the recommended congestion strategy among the other demonstrated strategies in this work.

References

1. Arora, V. K. Sharma, V. and Sachdeva, M. (2016). A survey on LEACH and other’s routing protocols in wireless sensor network. *Optik-International Journal for Light and Electron Optics*. 127(16), 6590-6600, DOI: 10.1016/j.ijleo.2016.04.041.
2. Arora, V. K. Sharma, V. and Sachdeva, M. (2019). A Distributed, Multi-Hop, Adaptive, Tree-based Energy-Balance Routing Approach. *International Journal of Communication Systems*, https://doi.org/10.1002/dac.3949
3. Dorigo M., Birattari M, Stutzle T (2006). Ant colony optimization. *IEEE Comput Intell Mag* 1(4), 28–39, DOI: 10.1109/MCI.2006.329691
4. Dorigo M., Birattari M(1999). Ant colony optimization. *In: Encyclopedia of machine learning. Springer*, 36–39. DOI: https://doi.org/10.1007/978-0-387-30164-8_22
5. Kim J-Y, Sharma T, Kumar B, Tomar GS, Berry K, Lee WH (2014). Intercluster ant colony optimization algorithm for wireless sensor network in dense environment. *Int J Distrib Sens Network* 10(4), 402–457. https://doi.org/10.1155/2014/457402
6. Liu X, He D (2014). Ant colony optimization with greedy migration mechanism for node deployment in wireless sensor networks”, *J Netw Comput Appl* 34, 310–318. https://doi.org/10.1016/j.jnca.2013.07.010
7. Wang H, Chen Y, Dong S (2016). Research on efficient-efficient routing protocol for WSNs based on improved artificial bee colony algorithm. *IET Wirel Sens Syst*. 7(1), 15–20. DOI: 10.1049/iet-wss.2016.0006
8. V. Sharma, A. Grover (2016). A Modified Ant Colony Optimization Algorithm (mACO) for Energy Efficient Wireless Sensor Networks. *Optik-International Journal for Light and Electron Optics*. 127(4), 2169-2172. https://doi.org/10.1016/j.ijleo.2015.11.117
9. Sert SA, Bagci H, Yazici A (2015). MOFCA: multi-objective fuzzy clustering algorithm for wireless sensor networks. *Soft Comput.* 30,151–165. https://doi.org/10.1007/s00500-014-1563-x
10. V. K. Arora, V. Sharma, and M. Sachdeva, “ACO optimized self-organized tree-based energy balance algorithm for wireless sensor network”, Journal of Ambient Intelligence and Humanized Computing, 1-13, 2019, https://doi.org/10.1007/s12652-019-01186-5
11. V. K. Arora, V. Sharma, and M. Sachdeva (2018). On QoS evaluation for ZigBee incorporated Wireless Sensor Network (IEEE 802.15.4) using mobile sensor nodes. *Journal of King Saud University –Computer and Information Sciences*, https://doi.org/10.1016/j.jksuci.2018.10.013

12. M. Faub, A. M. Zoubir (2013). Performance Analysis of Sequential Detection For Collision Avoidance in Sensor Networks. *IEEE, 2013*, DOI: 10.1109/ICASSP.2013.6638724

13. P. Singhal, A. Yadav (2014). Congestion detection in Wireless sensor network using neural network. *International Conference for Convergence for Technology*. DOI: 10.1109/ICT.2014.7092259

14. T. Pei, F. Lei, Z. Li, G. Zhu, X. Peng, Y. Choi, H. Sekiya (2017). A Delay-Aware Congestion Control Protocol for Wireless Sensor Networks”, *Chinese Journal of Electronics, 26*, DOI: 10.1049/cje.2017.04.010

15. A. Potdar, S. A. Ghodake (2017). A Cooperative Collision Warning using WSN in Vehicular Network. *IEEE, 2017*, DOI: 10.1109/ICCUBEA.2017.8463887

16. I. Iala, O. Zytoune (2017). Energy Based Collision Avoidance at the MAC Layer for Wireless Sensor Network. *IEEE International conference on Advanced Technologies*, DOI: 10.1109/ATSIP.2017.8075611

17. A. Khan, N. Javaid, A. Sher, R. A. Abbasi, Z. Ahmad, W. Ahmed (2018).Load Balancing and Collision Avoidance using Opportunistic Routing in Wireless Sensor Networks, *IEEE, 2018*, DOI: 10.1109/AINA.2018.00045

18. K Karenos, V Kalogeraki, S.V. Krishnamurthy (2005).Cluster-based Congestion Control for Supporting Multiple Classes of Traffic in Sensor Networks, *IEEE 2005*, DOI: 10.1109/EMNETS.2005.1469105

19. R Vedantham, R Sivakumar, S Park (2005). Sink-to-Sensors Congestion Control, *IEEE 2005*, DOI: 10.1109/ICCC.2005.1495018

20. D Lee, K Chung (2010). Adaptive Duty-cycle Based Congestion Control for Home Automation Networks. *IEEE Transactions on Consumer Electronics, 56*, DOI: 10.1109/TCE.2010.5439124

21. K Zhao, W Liu, M Wong, J Song (2010). Alternative Path-based Congestion Control in Many-To-One Sensor Networks, *CHINACOM, 2010*, INspec Accession Number: 11730435

22. H. Cha, K. Kim, S. Yoo (2011). A node placement algorithm for avoiding congestion regions in wireless sensor networks. *Third International Conference on Ubiquitous and Future Technology (ICUFN)*, DOI: 10.1109/ICUFN.2011.5949162

23. T S Kumaran, V. Sankaranarayanan (2011). Early congestion detection and adaptive routing in MANET. *Egyptian Informatics Journal, 165-175.*

24. S. Subburam, P. Sheik Abdul Khader (2012). Predictive congestion control mechanism for MANET. *Indian Journal of Computer Science and Engineering (IJCSE), 3.*

25. J Wei, B Pan, Y Sun (2012).A Congestion Control Scheme Based on Fuzzy Logic for Wireless Sensor Networks, *IEEE International on Fuzzy Systems and Knowledge Discovery*, DOI: 10.1109/FSKD.2012.6234353

26. Z. Li, W. Zou, T. Qi, “A cross-layer congestion control strategy in wireless sensor network (2012). *IEEE International Conference on Broadband Network and Multimedia Technology*, DOI: 10.1109/ICBNMT.2011.6155919

27. S. E. Ploumis, A. Sgora, D. Kandris, and D. D. Vergados (2012). Congestion Avoidance in Wireless Sensor Networks: A Survey. *IEEE Computer Society*, 234-239. DOI: 10.1109/PCC.2012.83

28. P. Gowthaman and R. Chakravarthi (2013). Survey on Various Congestion Detection and Control Protocols in Wireless Sensor Networks. *International Journal of Advanced Computer Engineering and Communication Technology (IJACET), 2.*

29. M. Amine Kafi, D. Djenouri, J. Ben Othman, A. Ouadjaout and N. Badache (2014). Congestion Detection Strategies in Wireless sensor Networks: A Comparative Study with Test bed Experiments. *Science Direct, EUSPN-2014*, 168-175.

30. A. Ghaffari (2015). Congestion control mechanisms in wireless sensor networks. *Journal of Network and Computer Applications*, Volume 52, 101-115, https://doi.org/10.1016/j.jnca.2015.03.002

31. N. Thrimoorthi and T. Anuradha (2016). Congestion Detection Approaches In Wireless Sensor Networks- A Comparative Study. *International Journal of Engineering Research and Development, 12*, 59-63.

32. Y. Chen, L. Zhao, and H. Chen (2016). Study of congestion control for wireless sensor networks based on small user. *11th International Forum on Strategic Technology (IFOST)*, DOI: 10.1109/IFOST.2016.7884115

33. A. A. Kadam, P. N. Chatur (2016).Literature review of congestion avoidance system in wireless sensor network. *Second International Conference on Science Technology Engineering and Management, IEEE*, DOI: 10.1109/ICONSTEM.2016.7560935
34. J. DzisiGadze, DelaliKwasiDake, and K. Diawuo (2013). Adaptive Congestion Control Protocol for Wireless Sensor Networks, *International Journal of Wireless & Mobile Networks (IJWMN)*, 5.

35. R. B. Jayakumari and V. J. Senthilkumar (2013). Priority Based Congestion Detection and Avoidance in Wireless Sensor Networks. *Journal of Computer Science*, 9 (3), 350-357. DOI: 10.3844/jcssp.2013.350.357

36. C. Li, J. Wang, B. Wang, Y. Han (2014). An efficient compressed sensing-based cross-layer congestion control scheme for Wireless Sensor Networks”, *Chinese Control and Decision Conference (2014 CCDC)*. DOI: 10.1109/CCDC.2014.6852244

37. S. Singh and K. Gupta (2014). Feedback Congestion Control Protocol for Wireless Sensor Networks: A Review. *International Journal of Science and Research (IJSR)*, 3.

38. T Kabir, N Nurain, Md. H. Kabir (2015). Pro-AODV (Proactive AODV): Simple Modifications to AODV for Proactively Minimizing Congestion in VANETs. *2015 IEEE International Conference on Networking Systems and Security (N SysS)*, DOI: 10.1109/N SysS.2015.7043521

39. P. Pinto, A. Pinto, M. Ricardo (2015). Cross-Layer Admission Control to Enhance the Support of Real-Time Applications in WSN”, *IEEE Sensors Journal*, 15. DOI 10.1109/JSEN.2015.2467329

40. M Khan, Dhat Shital M, Sayyad Ajij D (2016). Cross Layer Design Approach for Congestion Control in MANETs. *2016 IEEE International Conference on Advances in Electronics, Communication and Computer Technology (ICAECCT)*, DOI: 10.1109/ICAECCT.2016.7942633

41. T. Chand, B. Sharma, M. Kour (2016). TRCCTP: A traffic redirection based congestion control transport protocol for wireless sensor networks. *IEEE SENSORS*, DOI: 10.1109/ICSENS.2015.7370452

42. C. H. Kuo, T. S. Chen, Z. X. Wu (2016). Congestion Control under Traffic Awareness in Wireless Sensor Networks. *International Computer Symposium*, DOI: 10.1109/ICS.2016.0093

43. X. Yang, Z. Li (2016). Congestion control based on node and link in wireless sensor network. *35th Chinese Control Conference*. DOI: 10.1109/ChiCC.2016.7554692

44. O. Chughtai, N. Badruddin, M. Rehan and A. Khan (2017). Congestion Detection and Alleviation in Multihop Wireless Sensor Networks. *Wireless Communications and Mobile Computing*, https://doi.org/10.1155/2017/9243019

45. P. Kaur, J. Singh (2016). Congestion Avoidance in WSN Clusters using Token Bucket Algorithm. *International Journal of Advanced Research in Computer and Communication Engineering*, 5.

46. W. Chen, Y. Niu, Y.n Zou (2017). Congestion control and energy-balanced scheme based on the hierarchy for WSNs. *IET Wireless Sensor Systems*, 7. DOI: 10.1049/iet-wss.2015.0097

47. S. Paranjape, S. Barani, M. Sutaione, P. Mukherji (2016). Intra and inter cluster congestion control technique for mobile wireless sensor networks”, *Conference on Advances in Signal Processing (CASP)*, IEEE, DOI: 10.1109/CASP.2016.7746213

48. N. T. Panah, R. Javidan, M. R. Kharazmi (2016). A New Predictive Model For Congestion Control in Wireless Sensor Networks. *Journal of Engineering Science and Technology*, 12, 6, 1601-1616.

49. R. M. Kittali, S. K. Mahabaleshwar, A. V. Sutagundar (2017). Congestion controlled adaptive routing in wireless sensor network. *International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES)* IEEE, DOI: 10.1109/SCOPES.2016.7955695

50. N Aslam, K Xia, A Ali, S Ullah (2017).Adaptive TCP-ICCW Congestion Control Mechanism for QoS in Renewable Wireless Sensor Networks. *IEEE Sensor Letters*, 1, 6. DOI: 10.1109/LSENS.2017.2758822