29 Optimizing congestion collision using effective rate control with data aggregation algorithm in wireless sensor network

K. Deepa[1,a], *C. Arunpriya*[2] *and M. Sasikala*[3]

[1]Department of Computer Science and Artificial Intelligence, SR University, Warangal, Telangana, India

[2]Department of Computer Science, PSG College of Arts and Science, Coimbatore, Tamil nadu, India

[3]Department of Computer Science (PG), PSGR Krishnammal College for Women Coimbatore, Tamil nadu, India

Abstract

Wireless sensor networks (WSNs) offered promising opportunities for the development of ubiquitous and pervasive computing. However, the implementation of WSNs encountered many barriers and problems. These included the dynamic nature of network topology and the occurrence of congestion, both of which had a detrimental impact on network capacity utilization and overall performance. In WSN systems, the transmission of packets occurs from nodes with low congestion levels to nodes with high congestion levels, resulting in a decrease in energy levels for nodes located in close proximity to the sink nodes. The effective rate control with data aggregation (ERCDA) strategy employs an efficient data aggregation technique to enhance the equitable utilization of battery power across all nodes involved. The proposed methodology is executed on the NS2.35 platform and evaluated in terms of throughput, packet loss, end-to-end delay, and source data transmission rate adjustment. According to simulations, it has been shown that the use of ERCDA exhibits a higher degree of efficacy in comparison to conventional congestion-handling approaches.

Keywords: Wireless sensor networks, congestion control, data aggregation, rate control, ERCD

Introduction

WSNs are developed by connecting several sensor nodes with little energy. Each sensor may provide neighboring data through a wireless network at its distribution center. Because of its flexibility and authenticity, it uses correct information(Kafi et al., 2017). Thus, a reliable data exchange system was created. This network is utilized in medical practices, agricultural models, catastrophe monitoring, and more, and it depends on effective stability measures. Each sensor node has the essential data transfer capabilities (Wang et al., 2019). Even when nodes use full capacity, congestion may cause data loss, integrity issues, and unpredictable performance.

Ten years of study have concentrated on specialized protocols and effective strategies to manage huge data and limited bandwidth. Getting the signal from source to sink node with low loss is crucial (Yaakob and Khalil, 2016). Many researchers are interested in preventing network congestion, which is a major cause of data loss. Reduced congestion extends node life. Rate control is one of several traffic delay methods in the literature (Kafi et al., 2014). After discovering that RT traffic requires low latency and high consistency, it must be prioritized. Packets from a low-congested node to a highly-congested node in a WSN network reduce energy usage near the sink node. Variations in WPDDRC algorithm next hops between transmitter and receiver routing pathways might increase WSN unintentional energy usage. Overhearing diminishes emission sensor network efficacy (Kafi et al., 2014).

In a WSN network, packets transfer from low- to high-congested nodes, lowering energy near sink nodes. The suggested effective rate control with data aggregation (ERCDA) technique optimizes battery power utilization across all participating nodes using an effective data aggregation methodology. Network coding data aggregation reduces transmission delays and energy waste, increasing network performance. The transmission frequency is the number of data packets a node sends in one communication cycle (Cheng et al., 2013). Sensor nodes should not transmit more than one packet every round(Wang et al., n.d.). However, reduced transmission frequency boosted network channel capacity and throughput.

The network coding route combines data for transmission to the next hop, enhancing channel use and minimizing packet redundancy(Tan et al., 2019). When congestion develops, the packet dropping rate is raised and the node sends data via network coding. The parent node switches networking coding ON or OFF depending on packet precedence, node residual energy, and delay, according to adaptive network coding. Network coding uses random linear network coding(Swain and Nanda, 2019).

[a]k.deepa@sru.edu.in

Related work

(Sarode and Bakal, n.d.) DDRC approach exploits divergent rate variation between the sink and supplied nodes. This technique calculates a node's rate using global precedence and sink-node traffic rate changes. The traffic class's weighted priority and a node's diverging rate variance are used in WPDDRC. This method handles real-time and non-real-time data. This algorithm ranked legitimate traffic first(Ahmad Jan et al., 2018). Balanced traffic class priorities between nodes. The second technique relied on increased priority and derivative rate control. Rate control lowered packet loss and capacity utilization by controlling network congestion(Sumathi and Srinivasan, 2012) .

Monowar and Bajaber(2017) conducted a study in which they assigned priority to different traffic types and calculated the generalized processor (GP) for each node (Batra et al., n.d.). The aforementioned concept has also been used to monitor the provision of patient care in real-time. The protocol demonstrated enhanced quality of service (QoS) because to its high data transfer rate; nevertheless, it did not effectively address the network's hotspot problem. A rate management method for implanted wireless body area networks (WBANs) reduces congestion and hotspots, according to Monowar and Bajaber(Mazunga and Nechibvute, 2021).Health-monitoring network queue occupancy and traffic intensity data-controlled traffic congestion. Swain and Nanda (2019)prioritized packet transmission and hop-by-hop flow management in their research.

Sarode and Bakal (UC Santa Cruz UC Santa Cruz Electronic Theses and Dissertations. Adaptive Network Coding In MANET, (n.d.)) discussed priority node transmission in a long WSN and three congestion management techniques. The suggested methods ignored the network's node scheduling mechanism (Rezaee, Yaghmaee, and Rahmani, 2014). Rezaee and co-authors(2014),used queue management to reduce congestion in the healthcare system using WSN. They provided an AQM-based technique for stationary patients, but later developed a healthcare-aware optimized congestion avoidance and control protocol (HOCA) to prevent traffic congestion during critical patient transfer. Swain and Nanda presented traffic class preference-based adaptive rate regulation to reduce WSN congestion(Ghaffari, 2015). The algorithm uses unequal differences. The traffic class priority system prioritizes RT traffic. To identify requirements (Yin, Gui, and Zeng, 2019) presented a priority-based routing technique that combines RT and NRT traffic. Yaakob and Khalil used relaxation theory and max-min fairness to prevent congestion while transmitting critical medical data in real-time (Swain and Nanda, 2019).

To optimize throughput, REFIACC (reliable, efficient, fair, and interference-aware congestion control) was developed (Kafi et al., 2014). This method minimized interferences and ensured bandwidth fairness among nodes. Considering the variation between multiple path's infrastructure while scheduling reduced inter- and intra-route restrictions(Tshiningayamwe, Lusilao-Zodi, and Dlodlo, 2016). The greatest bandwidth was most efficiently used using linear programming. However, traffic priority was ignored and average throughput remained poor(Farsi et al., n.d.).

Proposed methodology

Effective rate control with data aggregation (ERCDA)

A graph G(V,E) may define the system model, where N is the number of nodes and E is the number of connections. E describes the communication connection between a V and b V, with sink node as the final receiver(Xie et al., 2018; Khattar et al., 2020). The link e(a, b) E represents the transmitter (Tr) and receiver (Rr) nodes a and b. Links are formed when the distance between nodes is less than the transmission range (Swain and Nanda, 2019). The sensor node sent application field data to the following node.

Data aggregation reduces transmission delays and energy use while increasing network performance. The transmission frequency is the number of packets a node delivers in one cycle. A sensor node should not transmit more than one packet every round. However, reduced transmission frequency boosted network channel capacity and throughput (Mazunga and Nechibvute, 2021). The network coding route combines data for transmission to the next hop, enhancing channel use and minimizing packet redundancy. In response to congestion, the packet dropping rate is raised and the node aggregates packets using the proposed algorithm.

The source node switches networking coding ON or OFF depending on file size, projected hub joins termination time, and network data flow, according to the suggested method. Turn off networkcoding for nodes that deliver file packets directly if the file size is less than the connection's maximum data rate and predicted link expiry time. The threshold value is utilized when data rate exceeds(Zhuang et al., 2019; Singh et al., 2020).

According on the packet rate, the nodes in the proposed technique determine whether to turn network coding ON or OFF. The transmission of data occurs in a direct manner between nodes. Nodes facilitate the implementation of network coding and are responsible for transmitting encoded data within networks, as stated in reference. Packets are encoded and transferred as linear combinations of the original packets. The receiver node decodes encoded packets to retrieve the originals. The total bytes of all packets to transmit are packet size.

$$Packet(sizeinbits) = 8 * Packet(size) \quad (1)$$

$$D = Data\ rates\ in\ bps \quad (2)$$

$$ET = Estimated\ link\ expiration\ Time \quad (3)$$

$$MDT = Max\ Data\ rate\ Transmit = D * ET \quad (4)$$

To build optimum paths with possible coding nodes, nodes must meet network coding requirements. Let's define certain notations before discussing network coding. Node an in data flow df routing is determined by source nodes and sink nodes sn. The single-hop neighbor set of node an is Ns(a). Forwarding and backward nodes in data flow df routing are shown by Forward(a, df) and Backward(a, df). Thus, if two flows meet at intermediate sensor node c, the intervening node may encrypt and send the data if the network condition is satisfied. The network packet flow is O1 and O2. The important and suitable requirements for system coding should be specified initially to identify coding possibilities. Network coding is achievable until the flows df1 and df2 intersect at node. Network coding collision occurs when different flows interfere.

Condition:

1: Existing noden$_1$ ∊ Backward (a, df$_1$) while n$_1$ ∊ N$_s$(m$_2$) Lm$_2$For(e,f$_2$) or n$_1$∊ For(e,f$_2$).

2: Existing node n$_2$ ∊ Backward (a, df$_2$) while n$_2$ ∊ N$_s$(m$_1$) Λm$_1$ For(e,f$_1$) or n$_2$∊ For(e,f$_1$).The network with many flows picks the route with the greatest coding possibilities that fits the condition. However, excessive coding at several conflicting nodes may prohibit the destination node from decrypting a native packet. At some time, flow df3 (black line) connects to the network. Node C1 meets the network coding requirement with df1 and df3 based on node C, and Node C2 meets it with df2 and df3. C1 receives O1 ⨀ O3 packets by encoding and delivering them over route df3. Additionally, node C2 encodes and sends packets O1 ⨀ O2 ⨀ O3 to L3 and N2 through pathways f3 and f2. As it overhears packets O1 and O2 from source nodes S1 and S2, destination node L3 decodes O3 from O1 ⨀ O2 ⨀ O3. If packets arrive at target node E2, it can decode packet O3 but not O2. Node C2 cannot be used as a coding node, as shown. Due to significant route coding, f3 affects the coding collision issue. Limits should be added to prevent code collisions. Machine learning-based bandwidth allocation method adapts to high-bandwidth traffic patterns to decrease latency. Artificial neural network (ANN) training and testing for high-bandwidth traffic of variable burstiness. Time(p,q) is packet flow time, k(p,q) is packet transmission, n(p,q) is packet count, BWreq(p,q) is desired bandwidth, and DR is DataRate.

Algorithm 1: Effective rate control with data aggregation (ERCDA)

Input: Set of path
Output: Selected path
Step 1: Initialize the parameters: service time (ST$_n^{sink}$), bdμ, are the traffic class priorities.
Step 2: Compute the mean service time n™ virtual queue in the sink node as:

$$\overline{ST}_n^{Sink}(t+1) = (1-\alpha)\overline{ST}_n^{Sink}(t) + \alpha.ST_n^{sink}$$

Step 3: Calculate the rate variance nt" virtual queue in the sink node using the formula

$$\Delta r^{sink} = \beta.r_{out}^{k} - r_{in}^{k}$$

Where,is the output rate of the kth connected child node of the sink.
The input rate of the kth parent node is
Step 4: Calculate the updated output rate of nth virtual queue in the kth parent node
Step 5: Calculate the update rate of nth virtual queue in the kth parent node propagated tothe Ith child node
Step 6: Continue Steps 2–Steps 5 until completion of the specified simulation period.
Step 7: Node has information to share.
Step 8: if
{
Step 9: Check for active neighboring nodes then
Step 10: Check if the data rate is higher than the maximum data rate.
If packet (sizeinbits) ≥ MDT
{
Execute network coding All packets into one coded Block or Frame are
represented by Ol, 02, 03,......0n
B(k) = O1 ⨀ O2 ⨀ O3…..n
B(k) =$\sum_{k=1}^{n} A_k$ x O_k
Else
Compute Traffic Load Intensity TLI $_{(i)} = \frac{TL(i)}{qmax(i)}$
End
Step 11: When flow dfl and df2 intersect at the node e, Network coding is feasible only
if
Existing node m € Backward (a, dft) while m1 € N$_s$(m2) L m2For(e,f2) or me For(e,f).

Existing node nz € Backward (a, df2) while n2 € N_s(m1) L m1) For(e, fi) or nz € For(e, fi).
}
Step 12: Eliminate Coding collision
// Training using ANN
Step 13: xp,g = {k(p.q). n(p.a). a(p.q). BWreq(p.q). duration(p.q)}
Step 14: duration(p+1.q)
Step 15: y=ANN ($x_{p,q}$)

Simulation results

In this section, the ERCDA technique is executed in network simulator version 2.35 (NS2.35) and 1000×1000m² simulation area with 50 nodes, 5GHz operating frequency, and 120 s simulation time. Its effectiveness is analyzed compared to the Healthcare-aware Optimized Congestion Avoidance and Control protocol (HOCA), Differentiated Rate Control Data Collection (DRCDC), and Congestion-aware Clustering and routing (CCR) techniques. The analysis is conducted based on throughput, packet loss, end-to-end (E2E) delay, and source data transfer rate adjustment.

Throughput
It is the amount of data accepted by the target within a time.

$$Throughput = \frac{Total\ amount\ of\ data\ accepted\ by\ the\ target}{Time} \quad (6)$$

Figure 29.1 illustrates the throughput (measured in kilobits per second) for the HOCA, DRCDC, and CCR methods throughout different simulation durations (measured in seconds). It is observed that the ERCDA produces a greater throughput compared to previous approaches. When the simulation duration is set to 120 s (seconds), the throughput achieved by the ERCDA algorithm is measured to be 525 kbps(kilobits per second), surpassing the performance of other techniques. This phenomenon occurs as a result of the allocation of priority levels to traffic classes at each virtual queue and the equitable distribution of bandwidth across all nodes in the network.

Packet loss
It is the amount of data dropped or missed during transfer.

$$packet\ loss = \frac{Amount\ of\ lost\ data}{amount\ of\ lost\ data + Amount\ of\ accepted\ data} \quad (7)$$

Figure 29.2 illustrates the percentage of packet loss for the HOCA, DRCDC, CCR, and ERCDA approaches over different simulation durations, measured in seconds. The findings suggest that the ERCDA approach has a lower incidence of packet loss in comparison to other strategies. If the simulation duration is 120 s, the ERCDA algorithm has a packet loss rate of 20%, which is the lowest among the other methods. Therefore, the ERCDA exhibits little packet loss as a result of its implementation of virtual queues and equitable allocation of bandwidth among nodes to effectively manage congestion inside the WSN.

End-to-end delay

It is the time taken for a data to be broadcasted from an origin to the sink.

$$E2E\ Delay = Time_{sink} - Time_{origin} \quad (8)$$

In this equation is the time at the sink while accepting the data and is the time at the origin while forwarding that data.

Figure 29.3 illustrates the end-to-end (E2E) latency, measured in milliseconds (ms), for the HOCA, DRCDC, CCR, and ERCDA approaches over different simulation time intervals, measured in seconds (s).

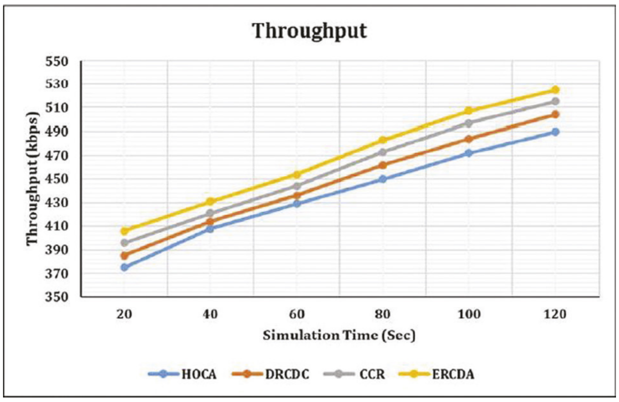

Figure 29.1 Throughput

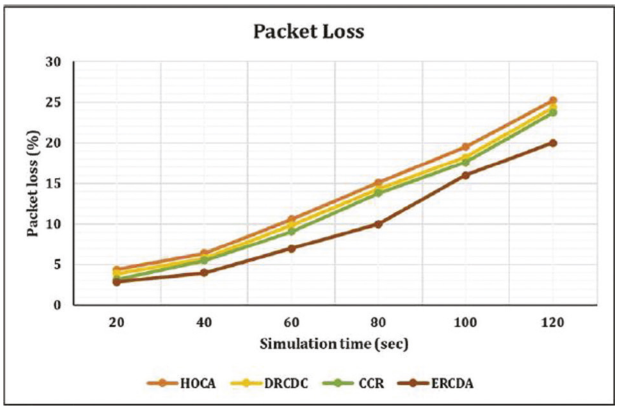

Figure 29.2 Packet loss

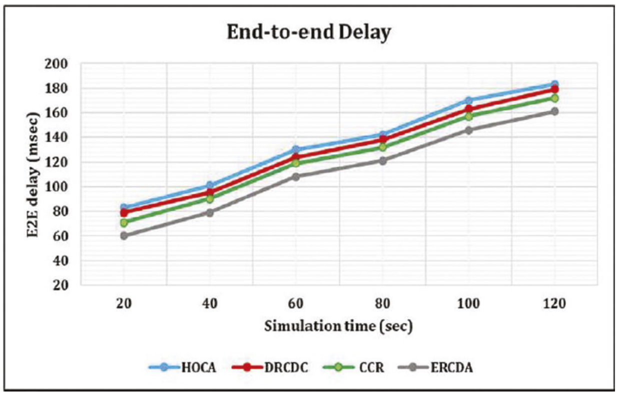

Figure 29.3 E2E delay

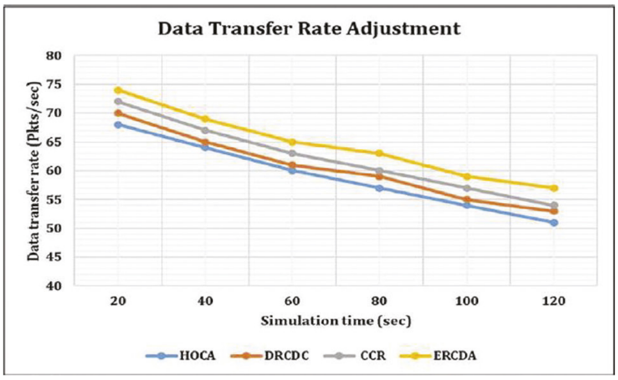

Figure 29.4 Data transfer rate

It is observed that the ERCDA approach has lower end-to-end latency in comparison to other strategies. If the duration of the simulation is set to 120 s, the end-to-end delay of the ERCDA is measured to be 161 ms, which is comparatively lower than the delays seen in other techniques. Hence, the least E2E is correlated with the greatest throughput and reduced packet loss.

Data transfer rate adjustment

It is the data transfer rate of origin, which handles the congestion and buffer overflow in WSN.

The data transmission rate (measured in packets per second) for the HOCA, DRCDC, CCR, and ERCDA approaches is shown in Figure 29.4. The simulation period (measured in seconds) is varied to observe the performance of these techniques. The findings of this investigation suggest that the ERCDA approach demonstrates superior data transfer rates as a result of its efficient rate adjustment and effective allocation of bandwidth. If the duration of the simulation is 120 s, it can be seen that the data rate of ERCDA is 57 packets per second, which surpasses the data rates of other methods. The ERCDA has the capability to progressively decrease the data transmission rate in relation to the starting transfer rate of the nodes. Therefore, it is essential to ensure that the traffic classes with the greatest priority are effectively disseminated without experiencing any congestion prior to decreasing the transfer rate.

Conclusion

This research introduces the ERCDA approach, which takes into account factors such as energy usage, battery power, and power management. Network coding is used in situations when the data rate exceeds a predetermined threshold value, taking into account the stated threshold value for the data rate. To optimize the equitable utilization of battery power, a proficient approach is implemented, including the aggregation of data, coding conditions, and coding collision mechanisms. In conclusion, the simulation results demonstrate that the efficacy of the ERCDA approach is superior to that of traditional congestion management strategies.

References

Ahmad Jan, M., Roohullah Jan, S., Usman, M., and Alam, M. (2018). State-of-the-art congestion control protocols in WSN: A survey. *EAI Endor. Trans. Internet Things*, 3(11),154379. https://doi.org/10.4108/eai.26-3-2018.154379.

Batra, U. Annual IEEE Computer Conference, IEEE International Advance Computing Conference 4 2014.02.21-22 Gurgaon, International Advanced Computing Conference 4 2014.02.21-22 Gurgaon, and IACC 4 2014.02.21-22 Gurgaon. n.d. *IEEE Int. Adv.Comput. Conf.(IACC), 2014 21-22 Feb. 2014, Gurgaon, India.*

Cheng, J., Ye, Q., Jiang, H., Wang, D., and Wang, C. (2013). STCDG: An efficient data gathering algorithm based on matrix completion for wireless sensor networks. *IEEE Trans.Wirel.Comm.*,12(2), 850–861. https://doi.org/10.1109/TWC.2012.121412.120148.

Farsi, Mohammed, Mahmoud Badawy, Mona Moustafa, Hesham Arafat Ali, and Yousry Abdulazeem. (2019). A congestion-aware clustering and routing (CCR) protocol for mitigating congestion in WSN. IEEE Access. 7: 105402–105419. pp. 1–18.

Ghaffari, Ali. (2015). Congestion control mechanisms in wireless sensor networks: A survey. *Journal of network and computer applications*. 52, 101–115.

Kafi, M. A., Ben-Othman, J., Ouadjaout, A., Bagaa, M., and Badache, N. (2017). REFIACC: Reliable, efficient, fair and interference-Aware congestion control protocol for wireless sensor networks. *Comp. Comm.*,101, 1–11. https://doi.org/10.1016/j.comcom.2016.05.018.

Kafi, M. A., Djenouri, D., Ben-Othman, J., and Badache, N. (2014). Congestion control protocols in wireless sensor networks: A survey. *IEEE Comm.Sur. Tutor.*,16(3),1369–1390. https://doi.org/10.1109/SURV.2014.021714.00123.

Mazunga, Felix, and Action Nechibvute. (2021). Ultra-low power techniques in energy harvesting wireless sensor networks: Recent advances and issues. *Scientific African*. 11: e00720. doi: https://doi.org/10.1016/j.sciaf.2021.e00720

Monowar, M. and Bajaber, F. (2017). Towards differentiated rate control for congestion and hotspot avoidance in implantable wireless body area networks. *IEEE Acc.*,5,10209–10221. https://doi.org/10.1109/ACCESS.2017.2708760.

Rezaee, A. A., Hossein Yaghmaee, M., and Masoud Rahmani, A.(2014). Optimized congestion management protocol for healthcare wireless sensor networks. *Wire. Per. Comm.*,75(1),11–34. https://doi.org/10.1007/s11277-013-1337-z.

Singh, J., Goyal, G., andGill, R. (2020). Use of neurometrics to choose optimal advertisement method for omnichannel business.*Enterp. Inform. Sys.*,14(2), 243–265, https://doi.org/10.1080/17517575.2019.1640392.

Sarode, Sambhaji S., and Jagdish W. Bakal. (2018). A data transmission protocol for wireless sensor networks: A priority approach. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*. 10(3): 65–73.

Sumathi, R. and Srinivasan, R. (2012). QoS aware routing protocol to improve reliability for prioritisedheterogeneous traffic in wireless sensor network. *Int.J. Paral. Emer.Distribut. Sys.*,27(2),143–168. https://doi.org/10.1080/17445760.2011.608356.

Swain, S. K. and Pradipta Kumar, N. (2019). Priority based adaptive rate control in wireless sensor networks: A difference of differential approach. *IEEE Acc.*,7,112435–11247. https://doi.org/10.1109/ACCESS.2019.2935025.

Tan, J., Liu, W., Wang, T., Zhang, S., Liu, A., Xie, M., Ma, M., and Zhao, M. (2019). An efficient information maximization based adaptive congestion control scheme in wireless sensor network.*IEEE Acc.*,7,64878–64896. https://doi.org/10.1109/ACCESS.2019.2915385.

Khattar, N., Singh, J., andSidhu, J. (2020). An energy efficient and adaptive threshold VM consolidation framework for cloud environment.*Wire. Per. Comm.*,113, 349–367.

Tshiningayamwe, L., Lusilao-Zodi, G. A., and Dlodlo, M. E. (2016). A priority rate-based routing protocol for wireless multimedia sensor networks. *Adv.Intel.Sys. Comput.*, 419, 347–358. https://doi.org/10.1007/978-3-319-27400-3_31.

UC Santa Cruz. UC Santa Cruz Electronic Theses and Dissertations. Adaptive Network Coding In MANET. (n.d.). https://escholarship.org/uc/item/0mw4r3hq.

Wang, Chonggang, Kazem Sohraby, Bo Li, Mahmoud Daneshmand, and Yueming Hu. (2006). A survey of transport protocols for wireless sensor networks. IEEE network. 20(3): 34–40.

Wang, F., Liu, W., Wang, T., Zhao, M., Xie, M., Song, H., Li, X., and Liu, A. (2019). To reduce delay, energy consumption and collision through optimization duty-cycle and size of forwarding node set in WSNs. *IEEE Acc.*,7,55983–55915. https://doi.org/10.1109/ACCESS.2019.2913885.

Xie, K., Wang, L., Wang, X., Xie, G., and Wen, J.(2018). Low cost and high accuracy data gathering in WSNs with matrix completion. *IEEE Trans.Mob.Comput.*,17(7),1595–1608. https://doi.org/10.1109/TMC.2017.2775230.

Yaakob, N. and Khalil, I. (2016). A novel congestion avoidance technique for simultaneous real-time medical data transmission. *IEEE J. Biomed. Health Informat.*,20(2),669–681. https://doi.org/10.1109/JBHI.2015.2406884.

Yin, Long, Jinsong Gui, and Zhiwen Zeng. (2019). Improving energy efficiency of multimedia content dissemination by adaptive clustering and D2D multicast. *Mobile Information Systems*. https://doi.org/10.1155/2019/5298508.

Zhuang, Y., Yu, L., Shen, H., Kolodzey, W., Iri, N., Caulfield, G., and He, S. (2019). Data collection with accuracy-aware congestion control in sensor networks. *IEEE Trans.Mob.Comput.*,18(5), 1068–1082. https://doi.org/10.1109/TMC.2018.2853159.