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Investigating Buffer Extension in Multi-Hop Networks for Packet Delay Improvement

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***Abstract*— Mesh networks are increasing day by day with their use. And common among them are Low power wide area networks (LPWAN) which have found significant use. In wireless sensors, in most configurations, the relay nodes do not generate their own traffic but simply pass on to the next node. As a cost saving measure, or to increase the coverage, relay nodes can admit traffic by acting as an access point as well as a bridge. Most devices available on the market have limited buffer sizes as a result, using these devices for this purpose may result in packet losses or delays due to the finite size of the buffer. An investigation is done on such a type of network and the end to end delay and buffer length dynamics are observed.**

***Index Terms*—Multihop Networks, Buffer and Mesh Networks**

I. Introduction

WITH the increase in the demand for connected devices, more and more devices are connected to the internet. This can be attributed mainly to advances in embedded systems. With the coming of the Internet of things (IOT), it is expected that the number of connected devices will increase to about 50 Billion by 2020. This paper presents a theoretical concept of the notion of buffer extension. The network structure is a two-tier network consisting of access points and their client hosts. The access points form the first tier which forms a multihop relay network from one access point to the other. These access points are known by many names, as servers, or also act as gateways. Two traffic classes. The client nodes access the access point randomly, therefore, the access point or relay node handles traffic from its cell as well as traffic from the other access points which it relays. Assuming the gateway has a finite buffer. In heavy traffic conditions, packet losses can be experienced as well as queuing delay for the higher class of packets. By using simulation, end to end delay in this architecture is observed as well as the changes in the buffer length. If no collision errors are experienced, packets will contend for buffer space. We observe through simulation the buffer of the source access point for high priority packets, the buffer size for the relaying node and the end to end delay specifically for the high-class packets. What is observed, at low node count, relay node buffer is stable and they is very little delay as would be expected by inutition.The scheme being investigated to improve on delay is similar to an implementation of a priority queue, however in this case, when the buffer has reached its maximum value and a priority packet arrives, instead of the high class packet queuing, hence being delayed, the packets give way, instead of the packets being discarded, they are transferred to the neighboring nodes. What is observed is that the buffer size has a lot of dynamics in large networks and a change in traffic characteristics ripples through the multi hop. The ultimate goal is to apply this observation in designing better large-scale wireless networks, with special interests in Ultra Wide Band (UWB) and LORA technologies.

II. Motivation

The motivation behind this to work is based on how the villages in developing nations are structured. Villages are normally clustered and spread throughout vast expance of land and these clusters would in turn have various inhabitants have little or no access to information and communication technologies. In order to provide such access at an affordable cost, Low networks deployed would have to carry a multiplicity of services like medical application, money transfer services as well as mobile money. Mesh networks and multihop become good candidates for these kinds of deployments settings. If the available Low power wide area networks could be deployed in Multihop fashion, within each village cluster, access can be achieved.

III. Problem Statement

Given a mixture of services in a single network, Quality of Service (QoS) becomes important. For example, a node in a network has to handle a mixture of Medical and environmental data, and priority has to be given to Medical traffic. With buffer size limitations, this poses a challenge in the event of high traffic load on the network which would result in packet loss and loss of data. Can the neighboring nodes around a relay cooperate in helping reduce packet latency?

IV. Literature Review

The authors in [1,2] study distributed storage architectures and a distributed storage model and a layered access control model which is distributed is developed. In [3] repair for the damaged storage node in the distributed storage system is considered. Work in [4] simulates distributed storage systems using network coding and the studies in [5] focus on how to better cope with node dynamics and failures. Authors in [6] propose a new infrastructure of storage overlay networks (SONs). This work is related to [7,8] in which buffer-aided physical-layer network coding (PLNC) techniques for improving data transmission. A network coding approach is used for mobile cloud storage, however in our work we look at high priority packets and latency and packet reduction.

V. System Description

A. Network Scenario

Villages in developing countries are arranged in clusters spread over vast geographical areas. Multihop networks interconnecting these clusters is one of the architectures that can provide digital services by using wireless access points. The network scenario is shown in Fig. 1.

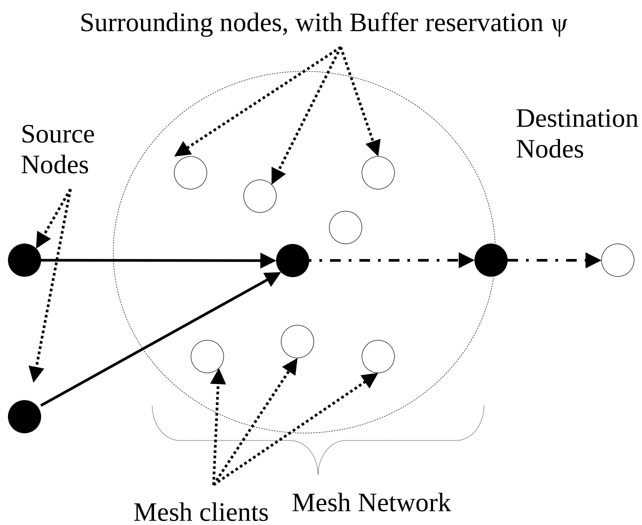

Fig. 1. Mesh network with the shaded nodes as main nodes and the non-shaded as mesh client nodes

To avoid congestion many deployments, have a maximum number of users that the access point can accommodate.

Equations (1-4) are all form of classical queuing theory.

B. Distributed Buffer Extension

In order to address the problem described above, we investigate a scheme of distributed buffer extension a relay node in a multihop network. Firstly, incoming packets of high priority to the relay node have stringent deadlines. Secondly packet loss. The issue of packet loss by evaluating how much through put is needed to send distribute the packets of low priority to be stored in the neighboring nodes. Extension of the buffer is done virtually based on queuing theory; the probability that there are N packets in an M/M/1/B queue is given by:

$$\mathbf{P_n} = \left(\frac{(\mathbf{1}-\boldsymbol{\rho})\boldsymbol{\rho}^{\mathbf{n}}}{\mathbf{1}-\boldsymbol{\rho}^{\mathbf{B+1}}}\right) \tag{1}$$

Given that the number of surrounding nodes is D and the amount of reserved buffer by each node be ψ. If each surrounding node reserves the same amount of memory, then the total available external buffer B’ becomes:

$$\mathbf{B' = D\psi} \tag{2}$$

If the amount of reserved space is not the same, then we have, total reserved storage

$$\mathbf{B'} = \sum_{k=1}^{J} \boldsymbol{\psi}_{\mathbf{k}} \tag{3}$$

Therefore, the virtual buffer extension becomes

$$\mathbf{P_n} = \left(\frac{(\mathbf{1}-\boldsymbol{\rho})\boldsymbol{\rho}^{\mathbf{n}}}{\mathbf{1}-\boldsymbol{\rho}^{(\mathbf{B+B'})+\mathbf{1}}}\right) \tag{4}$$

Where (B+B’) is the buffer extension due to the surrounding node density n, the probability of finding n packets. This has the effect of reducing the blocking probability and hence the packet loss. Whereas probability of Packet loss is improved by the virtual buffer extension, coding the incoming packet flow or the packets in the buffer gives a reduction in the expected latency and reduction in packet loss. There are several parameters which are considered when looking at quality of Service (QOS). These include data rate, bit error rate, packet error rate, duty cycle, desired battery lifetime and delay. These parameters all depend on the service being considered.

VI. Methodology

Packets in the buffer are cleared according to the class of traffic. Each class has a requirement for the number of packets to be cleared to maintain the delay requirement. Real time traffic and emergency data have stringent delay requirements.

A. Buffer clearing

Using a buffer clearing factor or scale parameter for each QoS class, the value of the clearing factor takes on values from 0-100%.For example highest priority may take a value of 100% or a factor of 1 signifying that all packets in the buffer should be cleared if an incoming packet of higher priority enters the buffer at the relay node.: For emergency packets or highest priority of packets, when the buffer is full, all the contents of the buffers should cleared. neighboring nodes.

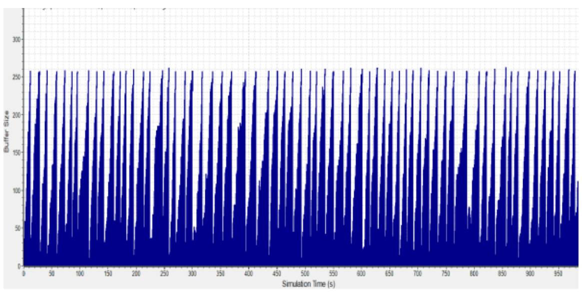

Fig. 2. Buffer Size vs Simulation time, 100 Nodes, Packet size 160Bits and Data Rate 9.375Kbps

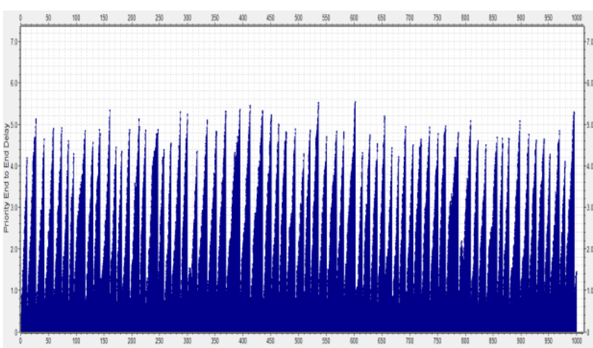

Fig. 3. Priority Packet Delay vs Simulation time, 100 Nodes, Packet size 160Bits and Data Rate 9.375Kbps

VII. Flow Chart

In real networks, to address the problem of QoS and congestion, several strategies are employed, including Trunk reservation and Virtual channel protection. The flow chart is as shown below, the preamble of the incoming packet is first read, priority information can be encoded in the preamble. If the Packet is not a high priority packet, its dropped if the buffer is full or inserted into the transmission buffer waiting for transmission. If however the incoming packet is high a priority with respect to the packets in the Buffer, calculate packet size. If the packet cannot fit into the buffer, the node density is checked. The node density ensures there are enough surrounding nodes such that packets can be transferred to the surrounding nodes, then the process is complete. If there is an alternative path, from the surrounding node, the packets are delivered to their destination. If the node density is less than a threshold, then the high priority packet is discarded.

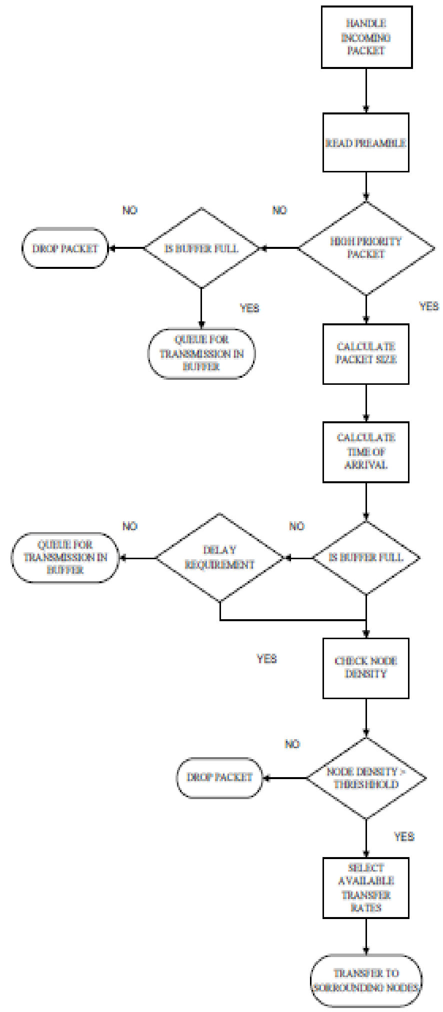

Fig. 4. Flow chart for Buffer extension

Fig. 2 and Fig. 3 show the result of implementing a buffer clearing scheme to improve on delay. In this instance the buffer size limit was 256 packets, and once a high-class packet arrives, all the packets in front are cleared to give way. The gaps in the graphs are the instances when the buffer is cleared and also when a high priority packet arrives. The queues quickly build up because of the high traffic intensity. Fig. 4 illustrates the flow chart for buffer clearing in order to improve on the delay.

TABLE I: RECEIVE AT SPREADING FACTOR 10 AND SEND AT DIFFERENT SPREADING FACTOR

BW (KHz)	SF	Bitrate (bps)	Latency(s)	Symbols
125	12	293	6.98	853
125	11	537	3.81	466
125	10	976	2.09	256
125	9	1757	1.17	143
125	8	3125	0.66	81
125	7	5468	0.37	46
125	6	9375	0.22	27

TABLE II: RECEIVE AT SPREADING FACTOR 8 AND SEND AT DIFFERENT SPREADING FACTOR

BW (KHz)	SF	Bitrate (bps)	Latency(s)	Sym
125	12	293	6.98	3408
125	11	537	3.81	1861
125	10	976	2.09	1021
125	9	1757	1.17	572
125	8	3125	0.66	323
125	7	5468	0.37	181
125	6	9375	0.22	108

VIII. APPLICATION TO IOT NETWORKS

Table I to Table IV above show the latency needed if LORA is used to clear the buffer for the incoming data. Part of the preamble length assuming perfect synchronization of 5 symbols. Meaning the data in the buffer has to be cleared within the remaining preamble time.

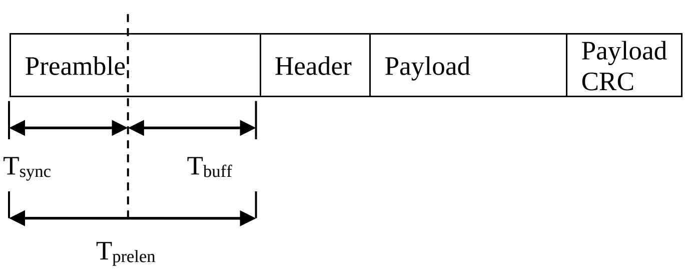

Fig. 5. LORA packet format

We don't know for certain at which point the receiver will synchronise with the preamble. Assuming there is perfect synchronization of the receiver with the incoming preamble, in the case of Lora, there are 10 preamble symbols [9]. It takes 5 symbols to synchronise with the preamble. The remaining 5 symbols are the time in which to clear the buffer in the node. Let the current size of the buffer be Q. The buffer length for most IOT devices is in hundreds of bytes. Some devices on the market.

T_{prelen} is the preamble duration
T_{buff} is the time to clear the Buffer.
T_{sync} is the receiver synchronization time

TABLE III : RECEIVE AT SPREADING FACTOR 12 AND SEND AT DIFFERENT SPREADING FACTOR

BW (KHz)	SF	Bitrate (bps)	Latency(s)	Symbols
125	12	293	6.98	214
125	11	537	3.81	117
125	10	976	2.09	64
125	9	1,757	1.17	36
125	8	3,125	0.66	21
125	7	5,468	0.37	12
125	6	9,375	0.22	7

TABLE IV: RECEIVE AT SPREADING FACTOR 6 AND SEND AT DIFFERENT SPREADING FACTOR

BW (KHz)	SF	Bitrate (bps)	Latency(s)	Symbols
125	12	293	6.98	13633
125	11	537	3.81	7442
125	10	976	2.09	4083
125	9	1757	1.17	2285
125	8	3125	0.66	1290
125	7	5468	0.37	723
125	6	9375	0.22	430

In the case of 256 Bytes Buffer, this has to be cleared within the remaining time after synchronization. A LORA packet may arrive at a node using one spreading factor and leave on another spreading factor to enable a higher data rate that incoming or current one at a node.

IX. SIMULATION

A. Parameters of the simulation

TABLE V: PARAMETERS OF THE SIMULATION

Parameter	**Value**
Channel	Ideal channel conditions
Access Technique	Aloha
Number of Gateway/Base stations	3
Number of nodes	10,20… 100
Node distribution	Uniform (0m,1000m)
Simulation Area	1000 m by 1000 m
Packet inter Arrival times	Exponential with mean 1,2,……10s
Gateway location	
	Gateway 1 (x-150m,y-840m)
	Gateway 2 (x-500m,y-500m)
	Gateway 3 (x-900m,y-250m)
Simulation Engine	Omnet ++

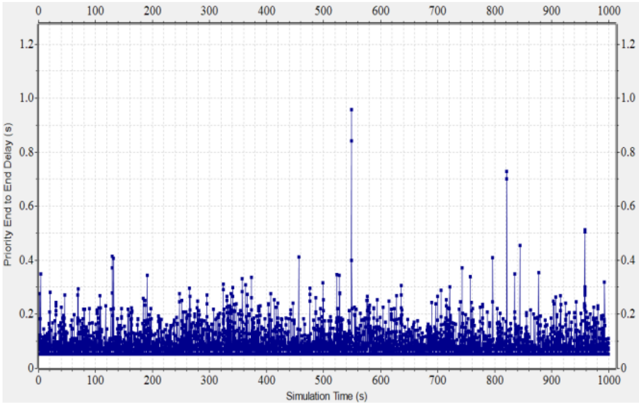

Fig. 6. Priority Packet Delay Vs Simulation time, 50 Nodes, Packet size 160bits and Data Rate 9.375Kbps destination node

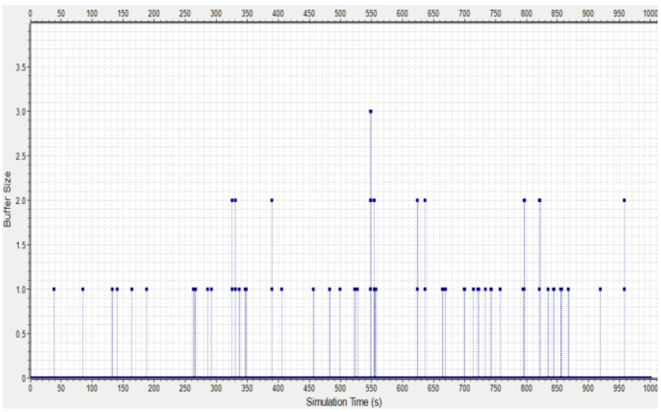

Fig. 7. Buffer Size Vs Simulation time 50 Nodes, Packet size 160bits and Data Rate 9.375Kbps at source Access node

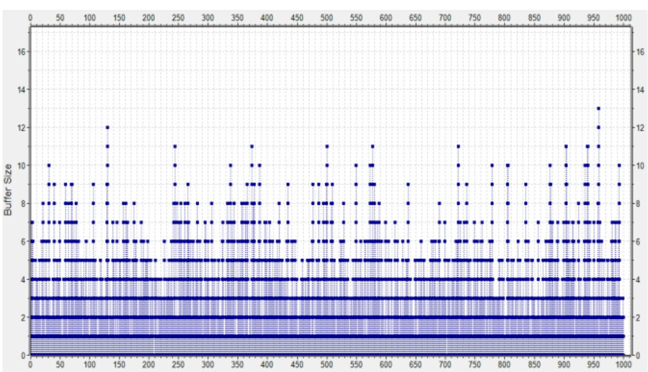

Fig. 8. Buffer Size Vs Simulation time 50 Nodes, Packet size 160bits and Data Rate 9.375Kbps at relay node

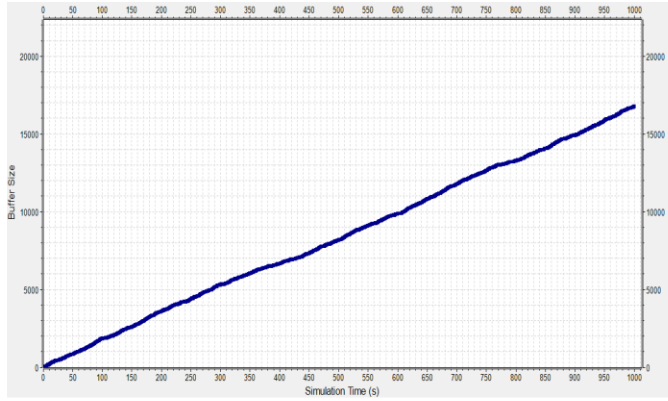

Fig. 9. Buffer Size Vs Simulation time 100 Nodes, Packet size 160bits and Data Rate 9.375Kbps

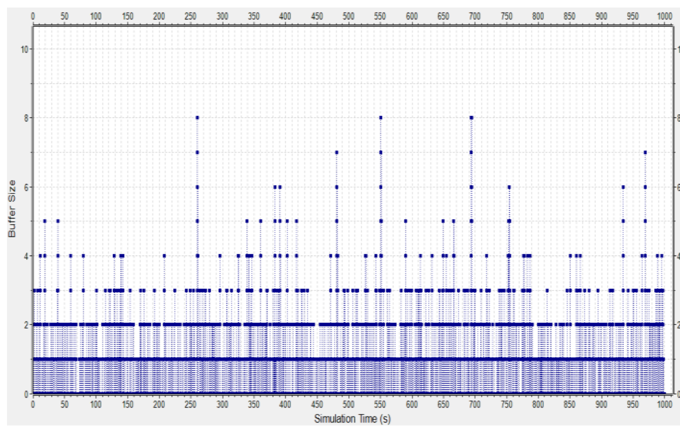

Fig. 10. Priority Packet Delay Vs Simulation time 100 Nodes, Packet size 160bits and Data Rate 9.375Kbps at source node

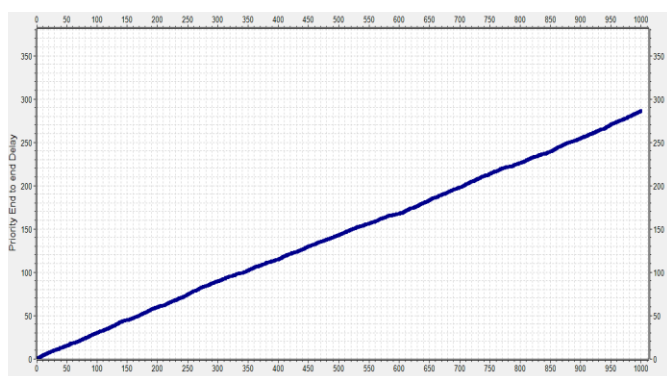

Fig. 11. Priority Packet Delay Vs Simulation time 100 Nodes, Packet size 160bits and Data Rate 9.375Kbps at destination node

X. Results and Analysis

From the results above, it can be observed that, at low traffic levels, the buffer fluctuations are low. In this way the high priority packets experience very low latency. As the traffic is increased, the relay node experiences an increase in traffic which causes the rapid fluctuations in the buffer size. These rapid fluctuations in turn affect the latency of the end to end delay. This may have implications on energy issues which will be looked at in future. Various topologies need to be tried out as well and evaluate their performance. The aim of this investigation is to observe three things: buffer behavior of the relay node/gateway, buffer behavior with time of the source node and the end to end delay for the high priority packets. The observation are as follows, the results shows when 50 nodes where considered with a packet size of 160 bits, a transmission rate of 9.375kbps. The observation was under high traffic with an exponential distribution with interarrival mean of 1s. In our observation, we assumed packets are nor lost due to contention and are received without loss. The access method is pure Aloha. The nodes are randomly distributed with a uniform distribution.9.375 kbps corresponds to LORA SF 6 nominal data rate. Fig. 6, Fig. 7 and Fig. 8 show the observation 50 nodes. Fig. 12 below shows the structure of the simulation network used and the parameters can be obtained from Table V above. Fig. 9, Fig. 10 and Fig. 11 show the performance at 100 nodes.

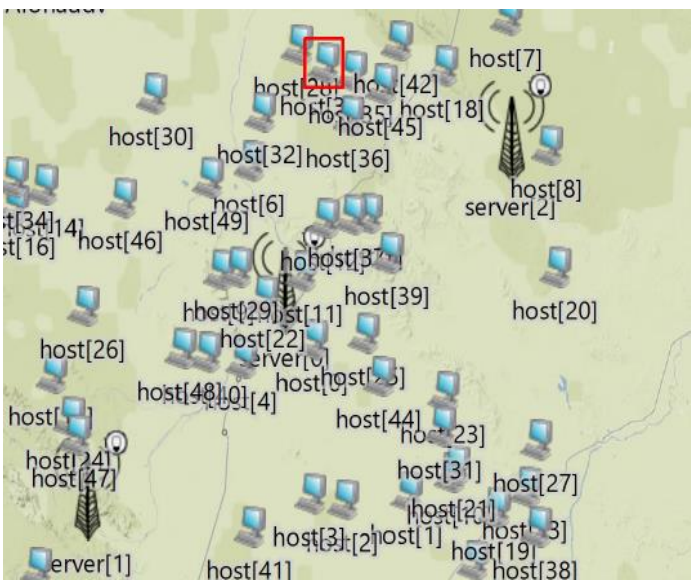

Fig. 12. Network with three Multihop node and surrounding host nodes

XI. Conclusion

This paper investigated latency in the form of end to end delay for high class packets, also observation of the Buffer size level at the relay node and also the source node. A scheme was discussed on the possible ways of improving latency and application of the scheme to IOT networks using LORA. The scheme relies on neighboring nodes having extra memory or storage where packets from a relay node can be sent during times of congestion or near congestion. Simulation shows some promise in implementation however a lot of factors still to be considered such as how surrounding nodes exchange buffer length ifnfomationits performance. This has been left for future study.

References

[1] Z. Ali and Q. Malluhi, "NSM: a distributed storage architecture for data intensive applications," 20th IEEE/11th NASA Goddard Conference on Mass Storage Systems and Technologies, 2003. (MSST 2003). Proceedings., San Diego, CA, USA, 2003, pp. 87-91.

[2] H. Wu, "Research on the Data Storage and Access Model in Distributed Computing Environment," 2008 Third International Conference on Convergence and Hybrid Information Technology, Busan, 2008, pp. 621-624.

[3] K. Chi, Z. Tian and Y. Zhu, "Node recovery schemes for minimizing repair time in distributed storage system with network coding," 2014 IEEE Wireless Communications and Networking Conference (WCNC), Istanbul, 2014, pp. 2857-2861.

[4] A. P. Majid Gerami, M. Xiao and D. Lin, "A study of distributed storage systems with network coding in wireless networks," 2014 IEEE International Conference on Communication Systems, Macau, 2014, pp.293-297.

[5] Y. Lin, B. Liang and B. Li, "Priority Random Linear Codes in Distributed Storage Systems," in IEEE Transactions on Parallel and Distributed Systems, vol. 20, no. 11, pp. 1653-1667, Nov. 2009.

[6] C.Wu and S. Lo, "Network-coded storages for cloud computing,"International Conference on Applied System Innovation (ICASI), Sapporo, 2017, pp. 469-472.

[7] J. Gu, R. C. de Lamare and M. Huemer, "Buffer-Aided Physical-Layer Network Coding with Optimal Linear Code Designs for Cooperative Networks," in IEEE Transactions on Communications, vol. 66, no. 6, pp. 2560-2575, June 2018.

[8] J. Shen, Y. Li, Y. Zhou and X. Wang, "Mobile Cloud-of-Clouds Storage Made Efficient: A Network Coding Based Approach," 2018 IEEE 37th Symposium on Reliable Distributed Systems (SRDS), Salvador, Brazil, 2018, pp.72-82.

[9] Semtech Corporation. LoRaTM Modulation Basics. 2015. http://www.semtech.com/images/datasheet/an1200.22.pdf.