A Reliable Adaptive Rate Congestion Control for Landslide Monitoring in Wireless Sensor Network

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***Abstract*—The emergence of Wireless Sensor Network (WSN) has developed significant potentials for real-time and remote monitoring systems, such as landslide monitoring, military surveillance as well as healthcare and home automation. Due to stringent requirements of real-time data transmission, most of these applications deserve high Quality-of-Services (QoS) assurance. However, sudden burst of traffic is likely to occur during WSN event detection, leads to buffer-overloaded problem, which is known as congestion. Obvious consequences include high packet loss that will severely degrade overall network performance. Such issues provide the motivation for this research, leading to the introduction of an Adaptive Rate Congestion Control (ARCC) mechanism, which is based on the integration of Selective Forwarding Node (SFN) and Relaxation Theory (RT). This integration technique has achieved huge reduction in packet loss rates (0.014%) as well as minimized the end-to-end delay that is proven to be within an allowable real-time threshold of 150 ms.**

***Index Terms*—Wireless Sensor Networks; Adaptive Rate Congestion Control; Landslide.**

I. INTRODUCTION

Recent developments in the fields of Wireless Sensor Networks (WSN) have attracted significant interest in remote monitoring services. This is triggered by the advancement in Microelectronic Mechanical Systems (MEMS) and wireless communication technologies that offers the tiny, cheap, and smart sensors. These sensors are deployed in a physical area to be monitored, and networked through wireless links and Internet [1]. This technology has provided unprecedented opportunities for variety of civilian and military applications such as environmental monitoring, battle field surveillance, and industrial process control [2-4]. In addition, WSN is used for assisting and improving various real-time related applications to provide continuous and remote monitoring services, targeting at applications in restricted areas where human intervention could be very risky and dangerous. For example, in industrial applications, WSN can be used to monitor manufacturing processes or the health condition of manufacturing equipment. In such scenario, the wireless sensors can be instrumented to production and assembly lines to monitor and control production processes as shown in Figure 1.

In addition, chemical plants or oil refiners can deploy several sensors to monitor the condition of their remote pipelines. Thousands of tiny sensors can be embedded into region of interest that is inaccessible by humans to monitor the condition of the machine to pre-detect any failures. Traditionally, industrial equipment is usually maintained on a scheduled basis, e.g. every three months for a regular check-up. This is way too costly and time consuming. According to statistics, US equipment manufacturer spends billions of dollars for maintenance every year [5]. This problem can be solved by conducting the maintenance based on the current machine health condition. The use of WSN in these domains is therefore, expected to significantly reduce the maintenance cost, increase machine lifetime, and most importantly save human lives.

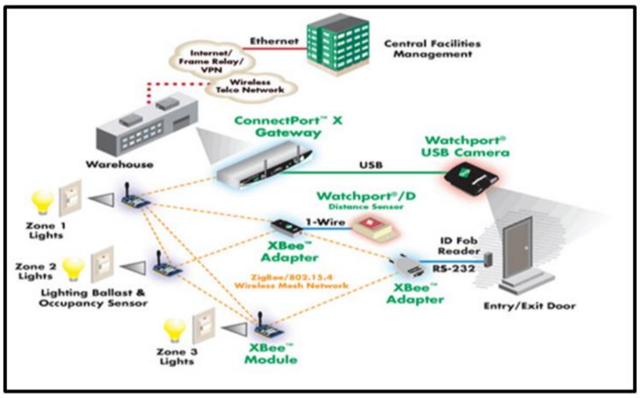


Figure 1: WSN is used in industrial process control to monitor manufacturing processes and equipment

A. *Problem Statement*

Basically, information sensing and data transmission in WSN follows many-to-one approach. Upon detection of any event, large number of sensor nodes will generate high reporting rates towards a sink node. This will trigger a sudden increase of network traffic that will lead to congestion. Since most of the applications in WSN span across remote and real-time data collections and information updates, congestion is the greatest obstacles for its effective deployment. High packet loss rate and transmission delay will jeopardize the performance of the underlying applications. Congestion causes huge energy spent at each sensor, as well as buffer overflow that may increase the number of packet loss and trigger high queuing delay. Due to stringent real-time requirements, these consequences cannot be afforded as it will degrade the QoS and overall network performance in such domains [1]. The afore-mentioned consequences have therefore prompted a crucial need for a reliable congestion control mechanism to mitigate the problem.

B. *Objectives*

The objectives of the proposed method are twofold:

- To develop a new adaptive rate congestion control mechanism that can prevent congestion and its subsequent issues in WSN.

- To ensure low packet loss rate and end-to-end delay during data transmission from sensors to sink node in order to maintain high QoS for real-time applications.

C. *Contributions*

The novelty of the proposed technique relies on the ability to reduce congestion by dynamically adjusting the sending rates based on the selected forwarding nodes. This is done using an efficient adaptive rate mechanism of Relaxation Theory (RT) which greatly helps in minimizing the number of packet loss and end-to-end delay. This mechanism prevents congestion from happening based on buffer occupancy and rate limiting approaches.

Even though congestion control protocols have been receiving great attention from the research communities, most of the methods exhibit high overhead during data transmission from source to sink the upstream nodes. Thus, the existing methods cannot support and maintain high QoS performance in WSN.

II. RELATED WORK

In communication networks, congestion control mechanisms can be divided into two categories; which are open-loop and closed-loop mechanism. In the former mechanism, policies are used to prevent congestion before it occurs, and the mechanism is either implemented by the source or destination node. On the other hand, the closed-loop mechanism tries to remove the congestion before it happens. Generally, this mechanism can be divided into congestion detection, congestion notification and rate adjustment as can be illustrated in Figure 2 and further elaborated in the following subsections.

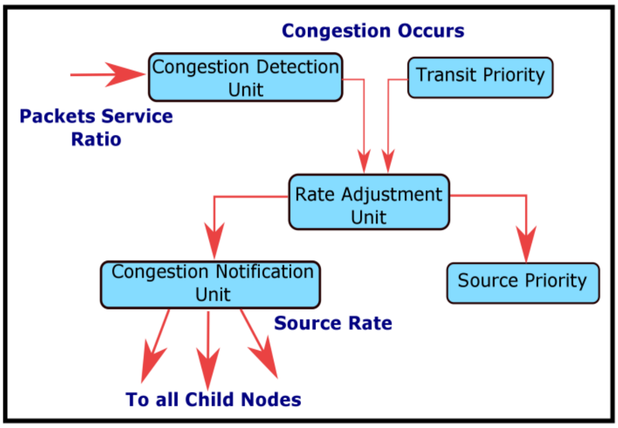


Figure 2: General architecture of the existing congestion control protocols

A. *Congestion Detection*

One of the mechanisms to detect congestion and forwards the traffic to the entire network is by using Dynamic Predictive Congestion Control (DPCC) [6]. This technique uses three rate adjustment approaches to acquire high throughput value which are Backward and Forward node Selection (BFS), Predict Congestion Detection (PCD) and Dynamic Priority-based Rate Adjustment (DPRA). Accordingly, the DPRA will ensure a more precise congestion discovery that led to high energy efficiency and the increase in the overall network throughput.

Other congestion detection schemes include the use of computer-vision based technology [12]. This approach integrates the digital images with sensors to detect motion. The authors in [13] also track congestion by capturing traffic images. This method however, extracts vehicle features in order to detect any congestion.

B. *Congestion Notification*

After congestion is detected, a transport protocol has to circulate the congestion information from the congested node to the upstream nodes. There are two types of congestions notification. First, is by using explicit congestion notification which manipulates special control messages to inform if there is a problem with the state of sending. The other approach is by using implicit congestion notification which does not impose any extra message for distributing congestion information. Basically, this technique piggybacks the congestion information on normal data packets.

C. *Rate Adjustment*

Upon receiving the notification, a sensor node has to adjust its transmission rate accordingly. Two common approaches used to avoid congestion are network resource management and traffic control. The network resource management minimizes congestion by intelligently controlling the resources (e.g. bandwidth) while the second approach reduces the congestion by adjusting the traffic at source or intermediate nodes. This is to limit the number of packets at a congested node while preventing high packet loss rate.

The other congestion control method is known as Adaptive Congestion Control Protocol (ACCP) [7], which identifies the presence of any congested node and broadcasts the information to the downstream nodes. The ACCP adopts the buffer occupancy and channel utilization strategy that detect congestion in a node. Using these strategies, the ACCPT is able to achieve high throughput and low energy consumption. While preserving high energy efficiency in the network, this proposed protocol found difficulties in providing accurate network resources adjustment during transmission of packets.

Besides that, Hop-by-Hop Cross-Layer Congestion Control Scheme (HCCC) [8] handles congestion occurrence by adjusting channel access priority in MAC layer and packets transmission rate of each node. In this approach, congestion detection is based on buffer occupancy ratio and congestion level of a local node. Even though HCCC can reduce the circulation of local congestion to its downstream node, its performance gets worse when the network scale increases. Therefore, it is not suitable for a large scale WSNs. Moreover, Hybrid Congestion Control Protocol (HCCP) [9] predicts congestion using packets delivery rate and remaining buffer size at each node.

In order to determine the current congestion degree at each node, every node is responsible to calculate its remaining buffer size and net flow. This information is then exchanged with its fellow neighbors. However, extra overhead is calculated since the nodes keep updating its current rate, which reduced the QoS. Thus, it is not suitable to be implemented in WSNs.

On the other hand, Prioritized Interface Queue Protocol (PIQP) [10] has fundamentally resolved the congestion problem based on buffer occupancy and also hop-by-hop backpressure mechanism. Congestion is avoided with the assistance of regular forwarding rate detection by sink node with an adaptive rate control algorithm. The PIQP architecture significantly lowered the rate of transit packets. Therefore, this approach has improved the energy efficiency and throughput. However, as the source nodes keep updating the current sending rate, additional overhead has also occurred. This situation is in contrast to the characteristics of WSN which has a limited power source in each node.

Furthermore, Relaxation Theory and Max-Min Fairness (RT-MMF) [11] detects congestion using buffer management and rate limiting approach. The RT works to ensure that no packets are left in the buffer by the end of transmission. Engineering level (EL) is the parameter that is responsible to determine the number of packets transmitted at one time based on packet arrival rates. However, in multiple nodes transmissions, RT produces very high EL which cannot be afforded in WSN due to limited resources. In this situation, the MMF proposed method consists of Progressive Filling Algorithm. This technique will lower the high transmission rates, reset them to zero and set to a constant rate once the threshold is exceeded. This RT-MMF method brings a remarkable improvement in performance which reduces both packet loss and transmission delay.

Our method is inspired from RT-MMF. However, the proposed method differs mostly in the selection of the forwarding nodes and also the buffer management applied to prevent congestion from happening.

III. PROPOSED METHOD

The proposed Adaptive Rate Congestion Control (ARCC) comprises two main parts, namely Selective Forwarding Nodes (SFN) and Relaxation Theory (RT). The SFN selects the forwarding node that can receive maximum rates from the previous node, while the RT is used to control the allocation of buffer space by postponing any excessive incoming packets to the next transmissions.

This approach begins with the generation of traffics by sensor nodes, followed by the selection of its forwarding node. As soon as the forwarding node chosen, RT technique is applied by postponing any excessive packets that exceed the threshold at any particular time. The overall overview of the proposed ARCC technique is shown in Figure 3, and the algorithm of the proposed architecture is illustrated in Algorithm 1.

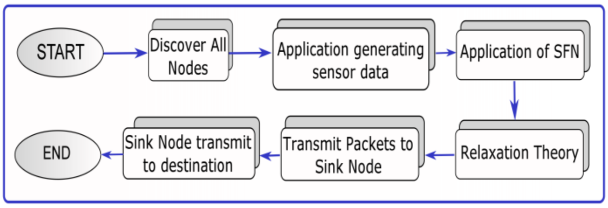
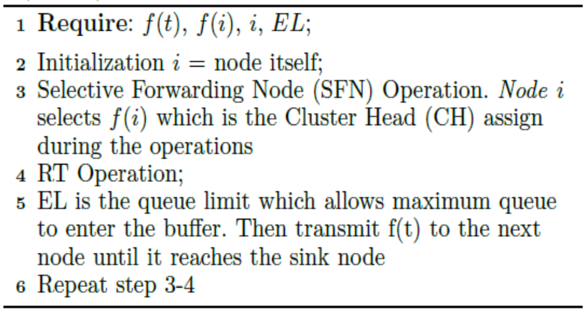


Figure 3 The proposed architecture for ARCC

Algorithm 1
Adaptive Rate Congestion Control (ARCC)



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1 Require: $f(t)$, $f(i)$, $i$, $EL$;
2 Initialization $i$ = node itself;
3 Selective Forwarding Node (SFN) Operation. Node $i$ selects $f(i)$ which is the Cluster Head (CH) assign during the operations
4 RT Operation;
5 EL is the queue limit which allows maximum queue to enter the buffer. Then transmit f(t) to the next node until it reaches the sink node
6 Repeat step 3-4
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A. Selective Forwarding Nodes (SFN)

Basically, data transmission in WSN follows the many-to-one traffic convergence towards the sink node. In this scenario, the sensors are generating continuous data transmission throughout the network. Mostly, each sensor node may have two types of generated traffic, which are source and transit traffic. The former is the packets produced from each sensor node, while the transit traffic is data generated from intermediate nodes.

Figure 4 shows that node 1 is a source node since it has only source traffic, while the remaining nodes; node 2, 3, 4, 5, 6 and 7 are source and transit traffic since they act as both, the source and intermediate nodes. Besides that, each node may have backward and forward neighbouring nodes. For example, the backward node of node 2 is node 1 since node 1 data is sent by node 2. The forwarding nodes of node 2 are node 4 and 5 where each node sends data to the upstream nodes.

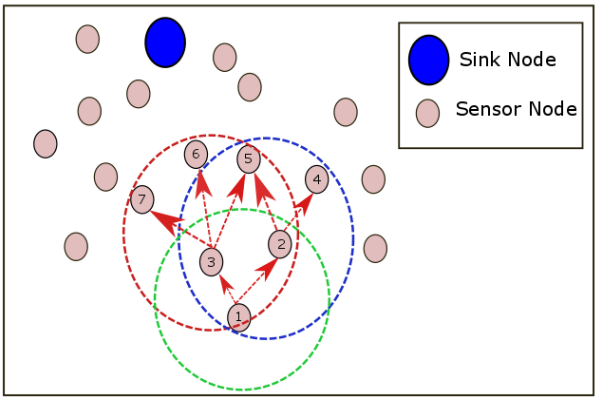

Figure 4: General network model for ARCC

Let us refer again to Figure 3 and Algorithm 1. *Node i* appoints *f(i)* to itself according to the node that can receive highest maximum rate *from node i*. In this case, we assign the selected node as Cluster Head (CH) since the instructions per second that can be received by the CH is much higher which is 829440 data per measurement compared to 3000 data per measurement for common nodes. The selected forwarding node becomes one of the intermediate nodes of *node i* to deliver packets to the sink node.

B. Relaxation Theory

This method is used to relax the excessive incoming packets so that they can be postponed for the next transmission slots. This is crucial in order to minimize packet loss rate during simultaneous data transmission. The Engineering Level (EL) is referred to as queue limit (*qlim_*) which is set to a maximum of 50 packets per transmission. Another variable is known as incomplete packet (*incomplete_P)* which reflects the number of packets that are still queued in the buffer at the end of transmission. These incomplete packets also imply that some of the packets have not arrived at their destinations. If the incoming packets (*len_*) is less than the queue limit (*len_< qlim_*), the packets will be directly transmitted to the next node. On the other hand, if the incoming traffic is larger than the queue limit (*len_> qlim_*), the maximum number of packets that can be transmitted in one session is equivalent to the *qlim_*. Then, the excessive packets are considered as incomplete packets (*incomplete_P = len_ - qlim_*), which are later bring forward for the next transmission. The total number of incomplete packets at every cycle of transmission can be calculated as (*X_tra* = *X_tra* + *incomplete_P*) where *X_tra* is a counter for incomplete packets which is initially set to zero. It is worth to mention that the postponement of any packets is still within the allowable unit delay (150ms for real-time applications).

For the next transmission, the node will always check if the condition of *(len_< qlim_)* exist, so that it can transmit extra packets (X_tra) from the previous transmission. Then in this case, *EL* = *EL* + *X_tra*. Otherwise, *EL* = *qlim_* as the incoming packets exceed the available capacity of the nodes. In the latter case, the *X_tra* will be increased by *X_tra* = *X_tra* + *incomplete_P*. These steps will be repeated until all the packets are transmitted to their desired destinations. All these steps can be represented in Algorithm 2.

Algorithm 2
Relaxation Theory-based ARCC

```
Require: $qlim\_, X_{tra}, incomplete\_P, EL$;
Initialization $X_{tra} = 0$, $incomplete\_P = 0$;
if $len\_ < qlim\_$ then
    Transmit as it is;
    EL == $len\_$;
else
    EL == $qlim\_$;
    $incomplete\_P = len\_ - qlim\_$
    $X_{tra} = X_{tra} + incomplete\_P$;
For the subsequent transmissions;
if $len\_ < qlim\_$ then
    EL = EL + $X_{tra}$;
else
    EL = $qlim\_$;
    $X_{tra} = X_{tra} + incomplete\_P$;
```

Additional variable of *blocked* and *unblocked* mechanism plays important roles in determining the correct time to deliver the packets to the next node. When *blocked = 1*, the packet will be blocked from any data transmission and vice versa.

IV. SIMULATION RESULTS AND ANALYSIS

In order to rate the performance of the proposed ARCC, we divide our analysis into four different performance metrics: average throughput, packet delivery ratio, average end-to-end delay and packet loss rate. Note that, the results presented in this paper are based on the landslide monitoring simulation setup as can be shown in Table 1.

Table 1
Simulation Setup

No	Input Parameters	Setup
1	Area of sensor field	300m x 300m
2	Number of sensor nodes	1-80
3	Number of Sink Nodes	1
4	Bandwidth	250 kbps
5	Packet Size	30 bytes
6	Simulation Time	600s
7	Radio propagation Model	TwoWay Ground
8	Antenna	OmniAntenna
9	Frequency Band	2.4 GHz
10	Transmission Range	50 meters
11	Energy Model	Battery

A. *Throughput versus Number of Sensor Nodes*

Throughput is among the important criteria used in measuring the effectiveness of the proposed ARCC. For performance comparison, we segregate the received throughputs with the traditional-WSN (TRD-WSN). Figure 5a shows the distribution of average throughputs within 600 seconds using 10 to 80 sensor nodes deployment. These sensor nodes send data simultaneously through some cluster heads and a sink node. Obviously presented in the figure, the TRD -WSN protocol has a slight increment in the throughput when the number of sensor nodes increase and simultaneously transmitting data at one time. In contrast, the performance of ARCC was improving by handling the congestion well enough to achieve much better performance by the constant increase in the throughput compared to the TRD-WSN protocol as demonstrated in Figure 5a.

The performance of the ARCC policy is dramatically improved since the buffer spaces are well managed with the assistance of RT mechanism by accepting more awaiting packets for these packets arrivals to be transmitted to the destination node. Obvious improvement can really be seen when the number of nodes approaching 60 sensor nodes. The pattern keeps increasing for ARCC which indicates a good sign. Even though the throughput for ARCC is lower than TRD-WSN, based on the observed pattern, we believe the throughput will be further increased with the increase in the number of nodes. On the other hand, the throughput for TRD-WSN remains the same towards increasing number of nodes.

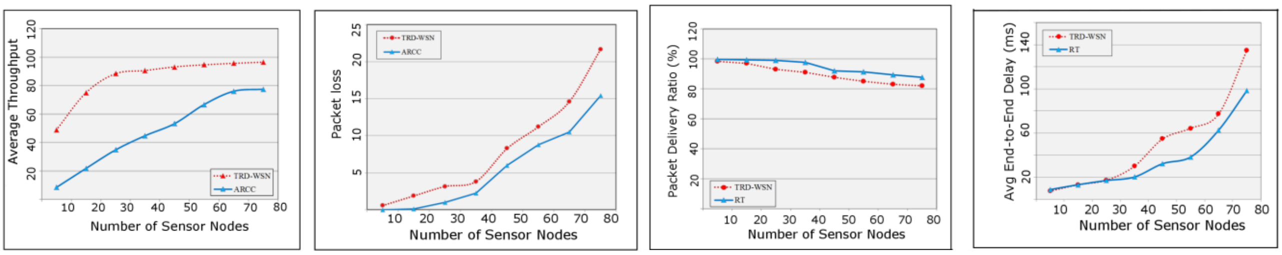

Figure 5: (a) Average Throughput (b) Packet loss (c) Packet Delivery Ratio (d) Average End-to-End Delay

B. *Packet Loss rate versus Number of Sensor Nodes*

Packet loss rate is an important parameter in any system that has a high risk of congestion. The environment that produces high packet loss rate is close to have congestion mode, besides it reflects poor network performance. In order to study the effectiveness of our method, we measure this metric in varying number of nodes. Figure 5b observers claim that the bigger the number of nodes, the higher is the percentage of packet loss rates. This is significantly true in high number of nodes (i.e.50 and above) where the resulted loss rate for TRD-WSN is drastically increased from 4% to more than 20% as shown in Figure 5b. On the other hand, our

ARCC method always has a lower packet loss rate compared to TRD-WSN. Therefore, the performance of our proposed solution is much better than the TRD-WSN in the sense that it produces low packet loss ratio for both less and larger number of nodes. The proposed designed method achieves as low as 0.014% and 15.4% packet loss rate in low and high number of nodes respectively.

C. Packet Delivery Ratio versus Number of Sensor Nodes

Figure 5c shows the ratio of the packets that are successfully delivered to destinations. This is measured with the increase number of sensor nodes. As a result, the increase in the number of sensor nodes will decrease the percentage of packet delivery in the network. We believe this is due to the increasing amount of sensor nodes which caused tremendous incoming traffic from the other nodes. Thus, the numbers of packets which are successfully arrived at the sink node have also increased. However, ARCC method exhibits better performance compared to TRD-WSN. This is due to the allocation of the incomplete packets (which exceeded the queue limit of 50 bytes per transmission) to the next transmission. Therefore, we believe that this proposed method is very helpful in lowering the packet loss rate and increasing the packet delivery ratio.

D. End-to-End Delay versus Number of Sensor Nodes

The resulting end-to-end delay can be seen in Figure 5d. During the landslide monitoring environment simulation, the proposed ARCC technique shows remarkable performance with over than 72.96% improvement compared to TRD-WSN. The proposed ARCC method is proven to exhibit low end-to-end delay since it relaxed the incomplete packets to the next transmission, instead to the next seconds. This is crucial as we believe that, there could be more than one transmissions occurred within a second.

V. CONCLUSION

This paper presents the performance of ARCC using Mannasim Framework. The results show that the proposed ARCC method always exhibits better performance than the TRD-WSN. This is due to the integration of selective forwarding nodes with RT that has significantly reduced the percentage of packet loss rate and the corresponding end-to-end delay. Through extensive simulation in NS-2, we also showed that our proposed model was able to manage many-to-one WSN dissemination approach. This study discovered that the RT mechanism can well exhibit excellent performance even during the busiest traffic. This has been proven in delay, as we preserved the safest delay threshold (<150 milliseconds) for real-time applications. Although we have increased the sensor nodes to optimum which is 80 sensor nodes based on our WSN-landslide monitoring scenario, the resulting delay is maintained to be low. Besides reducing the end-to-end delay, this technique also remarked a significance performance by producing low packet loss rates during less and high traffic generation respectively.

REFERENCES

[1] Zheng, J. 2009. *Wireless Sensor Networks:* 35–36. Hoboken,New Jersey: A John Wiley & Sons,Inc.,Publication.

[2] Akyildiz I. F., Melodia T., and Chowdhury K. R. 2002. A survey on wireless multimedia sensor networks, *Computer Networks (Elsevier),* 51(4): 921 – 960.

[3] Ben-Othman J. and Yahya B. Energy Efficient and QoS Based Routing Protocol For Wireless Sensor Networks. *Journal of Parallel and Distributed Computing,*

[4] Khedr A. M. and Osamy W. Mobility-Assisted Minimum Connected Cover In A Wireless Sensor Network. *Journal of Parallel and Distributed Computing,* 72(7):827-837, 2012.

[5] Revision of Part 15 of the Commission's Rules Regarding Ultra - Wideband Transmission Systems. First note and Order, Federal Communications Commission, ET – Docket 98 - 153, Adopted Feb. 14, 2002 released Apr. 22.

[6] Kahurke, A. S. 2012. Implementation of Priority based scheduling and congestion Control protocol in Multi-Hop WSN, *Volume-1*(2277-3878).

[7] DzisiGadze, J., DelaliKwasiDake, & Diawuo, K. 2013. Adaptive Congestion Control Protocol for Wireless Sensor Networks, *5(5).*

[8] Wu, G., Xia, F., Yao, L., Zhang, Y., & Zhu, Y. Hybrid Congestion A Hop-by-hop Cross-layer Congestion Control.

[9] Sheu, J. 2009. Hybrid Congestion Control Protocol in Wireless Sensor Networks, *25*(4).

[10] Mostafa Monowar, Rahman, M. Md. O. Pathan, A. K. and Hong C. S.., 2008. Congestion control protocol for wireless sensor networks handling prioritized heterogeneous traffic. In *Proceedings of the 5th Annual International Conference on Mobile and Ubiquitous Systems: Computing, Networking, and Services* (Mobiquitous '08). Belgium, Article 17.

[11] Yaakob, N., Khalil, I.; Kumarage, H.; Atiquzzaman, M.; Tari, Z., 2015. By-Passing Infected Areas in Wireless Sensor Networks Using BPR, in *IEEE Transactions on Computers*, 64(6): 1594-1606.

[12] Kerdvibulvech, C. 2015. An Innovative Use of Multidisciplinary Applications Between Information Technology and Socially Digital Media for Connecting People, *Communication of Computer and Information Science (CCIS),* 540: 60-69.

[13] Gerschuni M., Pardo, A. 2013. Bus Detection of Intelligent Transport System using Computer Vision, CIARP 2013, Part II, LNCS 8259, 59–66.