Implementation of RETSINA-based Congestion Control Technique in Realistic WSN Scenarios

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Abstract: Wireless Sensor Networks (WSNs) have utilized a huge amount research interest for their omnipresent applications to gather information from their sensing terrain. The gathered information will undergo in-network process and send to the remote sink. In this densely distributed network high packet flow occur near the sink due to the convergent nature of upstream traffic. Congestion may occur in the network and cause packet loss. Therefore congestion has to be controlled to prolong the sensor nodes lifetime. This paper presents RETSINA-based upstream congestion control protocol named, Agent-based Congestion Control Protocol (ACCP) for wireless sensor networks. The rate traffic analysis on each node is based on the priority index and the congestion degree of the node. In addition, we comprehensively evaluated the performance of congestion control with multi agent platforms as technology choices and investigated its latency and protocol overhead in three different scenarios.

Index – agent, congestion control, fairness, latency, protocol overhead, sensor nodes, upstream congestion control.

1. INTRODUCTION

WSN consists of large amounts of wireless sensor nodes, which are compact, light-weighted, and battery-powered devices that can be used in virtually any environment. With this data simple computations are carried out and communicate with other sensor nodes or controlling authorities in the network [18]. WSN have lately attracted in plenty of applications which include environment monitoring such as temperature, sound, pressure, vibration, pollutants, etc. at different locations, mobile object tracking, and navigation applications. All these applications consist of many inexpensive wireless sensor nodes that are capable of collecting, processing and storing various information. In wireless sensor applications all sensor nodes periodically report data to a single sink node which realizes a many-to-one communication model [4]. The congestion traffic is found in two streams, named downstream traffic and upstream traffic. The downstream traffic from the sink to the wireless sensor nodes are one-to-many communication model. The upstream traffic from sensor nodes to the sink is a many-to-one communication model.

The convergent nature of the upstream traffic in the upstream direction probably appears as congestion and the upstream traffic will create high bit rate with the development of diverse application in the WSNs. Thus congestion leads to packet losses and increased transmission latency and has direct impact on the energy-efficiency and congestion must be efficiently controlled. Every packet transmitted in the WSNs contains useful information, which can be utilized through packet-based computation and to enhance congestion control. The WSN packet computation has small packet forwarding rate and the forwarding computation capability is limited.

Most of the time the sensor nodes are modeled with limited energy, as a result the sensor nodes lacks recharging issues. But still wireless nodes packet-based computation is preferred since it is generally known that the computation utilizes reduced energy than the communication [2]. To attain the Quality of Service requirements, the network resources should be used in a fair and efficient manner. Moreover, techniques such as data compression, data fusion and aggregation become very useful in maintaining robustness. Due to the changes in node mobility and wireless channel failure, the WSN seems to be unreliable in nature. In order to efficiently use the WSN for real-time applications the issues related to the wireless protocols are reduced.

The rest of the paper is organized as follows. Section 2 reviews about the related literature and section 3 describes the detailed design of the RETSINA-based upstream congestion control protocol in wireless sensor networks. Section 4 details the experimental setup and analysis of latency and protocol overhead. Finally conclusion and future scope is given in section 5.

2. RELATED WORK

In this section, we review the prior work on improving the congestion control over WSNs. Chi-Tsun et al [5] proposed a delay-aware data collection network structure to minimize delays in the data collection process of WSNs. Two network formation algorithms are designed to construct the proposed network structure in a centralized and a decentralized approach. Simulation shows that the proposed network structure is able to shorten the delays in the data collection process significantly.

Marjan et al [11] formulated the problem of multiple targets coverage in WSNs as determining the sensing range of each sensor node to maximize total utility of the network. The utility model includes a logarithmic function of sensing range for the utility of each sensor node as an approximation to the number of targets it covers. A distributed price-based algorithm is derived from dual decomposition technique for each node to adjust its sensing range during iterations with static targets.

Yu et al [17] proposed a novel algorithm named Loss Inference based on Passive Measurement (LIPM), to infer WSN link loss performance. The algorithm passively monitors the application traffic between sensor nodes and sink, and then uses network tomography technology to infer the network internal performance.

Seong-hee et al [14] proposed a Coding-Aware Real-Time Routing (CARTR) that schedules coded and uncoded data in a link. Traditionally the coding-aware routing protocols have weakness regarding delivery of time-sensitive data in lossy links. Also, the improvement from network coding is negligible when using real-time data delivery. The proposed CARTR system is implemented and compared with IEEE 802.11 and the simulation reveals that the proposed system has a throughput improvement of 20%.

Jose et al [10] proposed an approach for interaction with real-world devices through a web services interface, allowing users to configure and apply various operations, including complex closed-loop techniques that monitor and act over any actuator in the WSN. The interaction between the client application and the motes are implemented with an AP to access services of the motes.

Rocio et al [13] relied on stochastic tools to develop selective message forwarding schemes. The scheme will depend on parameters such as the available battery at the node, the energy cost of retransmitting a message, or the importance of messages. The results contribute to identify the variables on other nodes, and have a greater impact on the overall network performance. Also, suboptimal schemes that rely on local estimation algorithms and entail reduced computational cost are also designed.

Chih-Kuang et al [3] introduced a distributed and scalable scheduling access scheme that mitigates high data loss in data-intensive sensor networks and can handle some mobility. The approach alleviates transmission collisions by employing virtual grids that adopt Latin Squares characteristics to time slot assignments. The algorithm derives conflict free time slot allocation schedules without incurring global overhead in scheduling.

Ing-Ray et al [8] developed an adaptive fault-tolerant QoS control algorithms based on hop-by-hop data delivery utilizing ‘source’ and ‘path’ redundancy, with the goal to satisfy application QoS requirements while prolonging the lifetime of the sensor system. Also a mathematical model for the lifetime of the sensor system as a function of system parameters including the ‘source’ and ‘path’ redundancy levels utilized are developed.

Gayathri et al [7] proposed a holistic approach to cognition in sensor networks, which can be achieved by incorporating learning and reasoning in the upper layers, and opportunistic spectrum access at the physical layer. They also provide framework based on knowledge and cognition that can be helpful to achieve end-to-end goals of application-specific sensor networks.

Ahmed et al [1] investigated the effectiveness of cluster-based routing protocols in extending the lifetime for energy-constrained WSN. Routing decisions affect the number of transmissions, the distance covered per transmission and the load placed on the intermediate nodes that participate in relaying the messages. The study focused on common parameters of well-known cluster based routing protocols.

3. RETSINA-BASED UPSTREAM CONGESTION CONTROL ALGORITHM

This work has made an attempt to address, among various problems, the issues of getting optimal delivery path to improve the protocol overhead and minimizing the packet delay by applying intelligent agent-based technique. To achieve this, a method of getting efficient congestion control protocol satisfying the QoS requirements like throughput in the form of packet delivery ratio, as well as optimizing network resources such as packet delay, and also to improve the performance of the network in terms of computationally feasibility, using a multi-agent based intelligent technique is proposed. The principal idea to design an efficient congestion control protocol is to offer rate traffic analysis on each node based on the priority index and the congestion degree of the node.

An upstream congestion control for a WSN has single-path and multi-path routing. In single-path routing, a child node can have a single parent node and all the packets are forwarded from the child node to the parent node based on certain policy [15], and is shown in figure 1. In this, the entire child node has a single path towards the parent node.

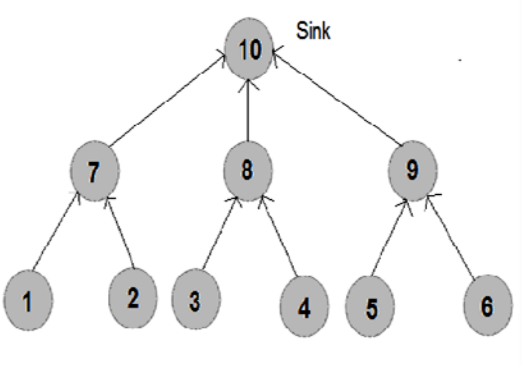

Figure 1 Single-path Routing

In multi-path routing, a child node can have a multiple parent nodes and all the packets are forwarded from the child node to the parent node based on certain policy including uniform forwarding or proportional forwarding [6]. Figure 2 shows a multi-path routing, in which nodes 2 and 4 have multiple parent nodes.

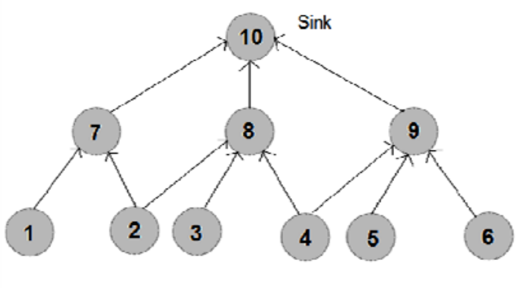

Figure 2 Multi-path Routing

In this work a single path routing is considered, where the wireless sensor nodes are supposed to generate continuous data and may be used to form many-to-one convergent traffic in the upstream direction. All the wireless sensor nodes have two types of traffic; named the source traffic and the transit traffic. The source traffic is generated locally at each wireless sensor node. The transit traffic is generated from the other wireless sensor nodes [16]. The entire wireless sensor node can act as a source node or an intermediate node. If a wireless sensor node has child nodes and transit, then it will act as a wireless sensor source node as well as an intermediate node. If there is no child node, then it will only be a wireless sensor source node and has only the source traffic, which is generated locally.

Figure 3 shows the queuing model at a particular wireless sensor node *i* with the single-path routing. The transit traffic of wireless sensor node *i* is received from its child nodes such as wireless sensor node *i* – 1 through its MAC layer. The transit traffic is denoted by r^i_t. The locally generated source traffic at the wireless sensor node *i* has the rate of r^i_s. Both the transit traffic and source traffic will converge at the network layer before being forwarded to the wireless sensor node *i* + 1, which is the parent node of wireless sensor node *i* [15].

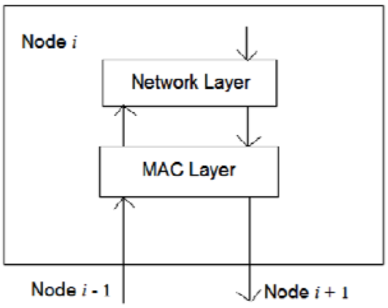

Figure 3 WSN Node

The packets are queued at the MAC layer if the total input rate exceeds the packet forwarding rate at the MAC layer. The packet forwarding rate of the MAC layer is represented by r^i_f. The packet forwarding rate depends on the MAC protocol alone [15]. The total input traffic rate r^i_m at the wireless sensor node *i* is the sum of the transit traffic at wireless sensor node *i* and the source traffic at wireless sensor node *i*, and is given in the following equation 1.

$$r^i_m = r^i_s + r^i_t \qquad (1)$$

By assuming the CSMA protocol, the number of active wireless sensor nodes as well as their traffic density influences the packet forwarding rate r^i_f. Let r^i_{in} be the packet input rate towards the wireless sensor node *i* from the wireless sensor node *i* – 1, and r^i_{out} be the packet output rate from the wireless sensor node *i* to the wireless sensor node *i* + 1.

If $r^i_{in} < r^i_f$, then $r^i_{out} = r^i_{in}$, and if $r^i_{in} > r^i_f$, then r^i_{out} is close to r^i_{in} [16]. Therefore the packet output rate at wireless sensor node *i* can be obtained from the following equation 2.

$$r^i_{out} = \min (r^i_{in}, r^i_f) \qquad (2)$$

From equation 2 it is clear that the packet output rate at wireless sensor node *i* can be indirectly reduce through reducing the packet input rate to the wireless sensor node *i*. In this work, a multi-agent system based intelligent upstream congestion control protocol has been developed.

The problem of single-path upstream congestion control in WSNs through the traffic control is proposed by introducing a new multi-agent system based approach to control the traffic in the upstream congestion. A Reusable Task-based System of Intelligent Networked Agents (RETSINA) [12] is a cooperative multi-agent system that consists of three classes of agents: interface agents, task agents and information agents. RETSINA provides a domain-independent, componentized, and reusable substratum to (a) allow heterogeneous agents to coordinate in a variety of ways and (b) enable a single agent to be part of a multi-agent infrastructure. RETSINA provides facilities for reuse and a combination of different existing low-level infrastructure components, and it also defines and implements higher level agent services and components that are reconfigurable and reusable.

An upstream congestion control model by using RETSINA multi-agent named Agent-based Congestion Control Protocol (ACCP) is proposed. ACCP reduce the packet loss by its intelligent scheduling schemes. Figure 4 illustrates the proposed congestion control model in a wireless sensor node. ACCP consists of four components: Execution Monitor, Communicator, Planner, and Scheduler [9].

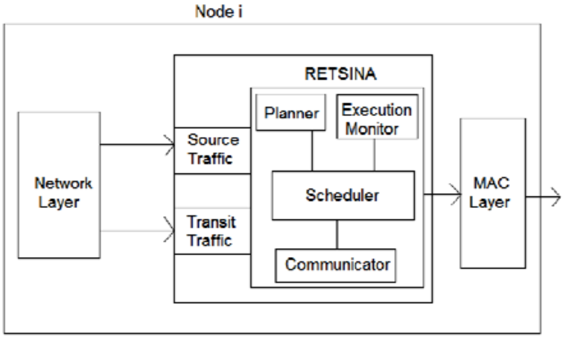

Figure 4 Proposed Congestion Control Model

The execution monitor identifies the congestion based on the packet arrival time (t_a) and packet service time (t_s) at the Medium Access Control (MAC) layer. The packet arrival time (t_a) is the time interval between two subsequent packets arrived from any source and the packet service time (t_s) is the time interval between arrival of packets at the MAC and its successful transmission. These two parameters are monitored at each node by the execution monitor on a packet-by-packet manner. From this, a congestion index (Cx) is calculated and is defined as the ratio of average packet service time over average packet arrival time at each wireless sensor node. The congestion index at node *i* is given by equation 3.

$$\mathbf{Cx}_{(i)} = \frac{t_s}{t_a} \qquad (3)$$

The execution monitor also takes the agent's next intended action and prepares, monitors, and completes its execution. The communicator module communicates all the notifications at each wireless sensor node in the packet header to be forwarded. From the congestion index the communicator module computes a global congestion priority index by summating source congestion priority index and the global congestion priority index of the lower level wireless senor nodes.

The planner receives goals through communication message packets and finds alternative ways to fulfill them. The planning component is reusable and capable of accepting different planning algorithms in an intelligent way. The scheduler has two queues for the source traffic and the transit traffic. By adjusting the scheduling rate the congestion can be reduced.

The scheduling algorithm uses the earliest deadline-first heuristic. A list of all actions is scheduled and the action with the earliest deadline is chosen for execution. When a periodic action is chosen for execution, it is reinstated into the schedule with a deadline equal to the current time plus the action's period.

The four modules of RETSINA multi-agent are implemented for the upstream congestion control as autonomous threads of control to allow concurrent planning and scheduling actions, and execution in an efficient way. Furthermore, all modules are executed as separate threads and are able to execute concurrently. So almost all the packets are forwarded to the next wireless sensor node without any loses.

4. SIMULATION RESULTS

The simulations are implemented with three different scenarios using wireless sensor nodes communicating via IEEE 802.11 MAC layer protocol model with a transmission range of 200 meters. The simulation environment is implemented in the NS-2, a network simulator that provides support for simulating wireless networks. The simulations are carried out using a sensor environment roaming over a simulation area of 1500 meters x 1500 meters flat space operating for 600 seconds of simulation time. The network topology used in the simulation is a simple single-path routing model. Nodes in this simulation move according to the Random Way Point Mobility model [16], which is in random direction with speed ranges that vary from 0 m/s to 20 m/s and the buffer size is set to 100 packets.

The mobility of different levels is obtained by changing the maximum node speed with a pause time of one second. The sensing node in WSN is usually stationary or moves with a walking speed of about 1 m/s. We evaluate the performance of the ACCP on a wireless network environment in the following three different scenarios.

Scenario 1 - A wireless environment consisting of 60 wireless sensor nodes.

Scenario 2 - A wireless environment consisting of 80 wireless sensor nodes.

Scenario 3 - A wireless environment consisting of 100 wireless sensor nodes.

Performance has been analyzed below for the metrics latency and protocol overhead.

Latency

Average latency is a measure of the average time between initiating a route discovery for a wireless sensor node to transmit and successfully setting up a route for the data transmission. For all the simulation scenarios, the maximum response time is set to 10ms, which has a large impact on the average latency.

Figure 5 shows the analysis of latency on ACCP under all the three different scenarios with wireless network environment. The average latency for the scenario 3 has the highest compared to that for the other two scenarios. But the latency lowers when there is an increase in pause time, which is almost common in all the simulation scenarios. A system with reduced latency will increase the energy-efficiency of the wireless sensor nodes and will definitely extend the system lifetime. Comparing the three scenarios the proposed ACCP algorithm has an average latency of about 1.5833 milliseconds.

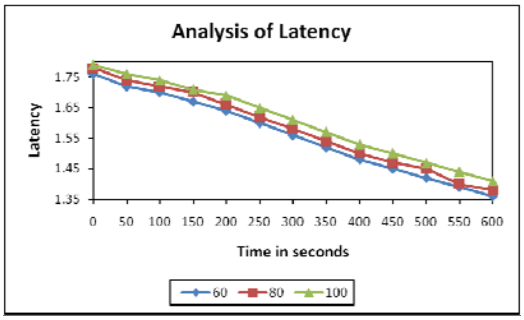

Figure 5 Analysis of Latency for different Scenarios

Protocol Overhead

Protocol packet overhead is the ratio of the number of protocol packets originated or forwarded, related to the route creation process that are received by a node per data delivery. This metric indicates the percentage of the total protocol messages transmitted for data forwarding.

Figure 6 shows the analysis of protocol overhead on ACCP under all the three different scenarios with wireless network environment. During the simulation, it is seen that most of the time all the graphs are in overlapped form. For the entire simulation scenario the protocol overhead rises linearly during the simulation. The proposed ACCP has an average protocol overhead of 2.84 MB, and as the number of wireless sensor nodes increases, the control message transmitted is minimized, by means of reducing the number of forwarding nodes.

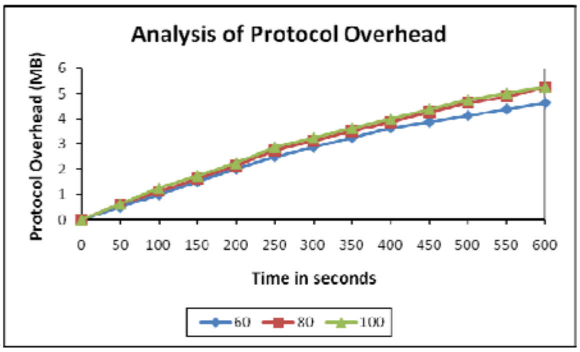

Figure 6 Analysis of Protocol Overhead for different Scenarios

5. CONCLUSION

In this paper, an agent-based upstream congestion control protocol is implemented in NS 2 with different scenarios. This is a distributed algorithm that seeks to assign fairness and rate efficiently to each node. This algorithm very aggregately monitors each nodal input and output traffic rate. The algorithm varies the transmission rate of the node and its upstream nodes. This introduces node priority index and is simulated for a single-path routing environment. The simulation shows that the upstream algorithm provides remarkable results, and is able to attain fairness for all the sensor nodes in the network and acquire the transmission rate quickly. This work can be extended for multi-path routing environment too. Other intelligent agent based approach can also be used with the fairness congestion control algorithm to further reduce packet loss and which in turn improves energy-efficiency, and provides lower delay. This work can also be extended to integrate data aggregation schemes to reduce further energy consumption and to increase the battery life-time of the sensor node.

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