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Bandwidth and Energy Management in Wireless Sensor Networks

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***Abstract*— The emergence of sensor networks as one of the dominant technology trends in the coming decades has posed numerous problems regarding the Quality of Service (QoS) parameter to researchers. These QoS parameters are often found to be as limited resources. Hence to effectively utilize these limited resources, we propose a technique to manage two of the most basic QoS parameters of sensor networks, they are bandwidth and energy. We propose bandwidth management by implementing rules that guide the data streams to a specific data rate, so as to treat different data to its own credit. To manage energy we present GAF algorithm that effectively reduces energy consumption of the nodes keeping a constant level of routing fidelity. The simulation is run on NS-2.34 with 35 nodes in total. The simulation results obtained show that the combination of the both bandwidth and energy in management performs better than the existing protocols.**

***Index Terms*— GAF, hop-by-hop, rule system, wireless sensor networks.**

I. Introduction

Wireless sensor networks (WSNs) have emerged as a new class of information technology infrastructure where computing is embedded into the physical world [1, 16, 17]. A WSN consists of a large number of spatially distributed devices with computing and sensing capabilities, i.e., motes, which form an ad-hoc wireless network for communication. Applications of WSNs include building control [18], environmental monitoring [22], traffic control [20], manufacturing and plant automation [23], service robotics [19], and surveillance [21]. The standardization of communication protocols for sensor networks, namely IEEE 802.15.4 and ZigBee, has facilitated the effort to commercialize WSNs.

The design space for routing algorithms for WSNs is quite large and we can classify the routing algorithms [6, 29] for WSNs in many different ways. Routing protocols are classified as node centric, data-centric, or location-aware (geo-centric) and QoS based routing protocols. Most Ad-hoc network routing protocols are node-centric protocols where destinations are specified based on the numerical addresses (or identifiers) of nodes. In location aware routing [15] nodes know where they are in a geographical region. Location information can be used to improve the performance of routing and to provide new types of services. In QoS based routing protocols data delivery ratio, latency and energy consumption are mainly considered. To get a good QoS (Quality of Service) the routing protocols must possess more data delivery ratio, less latency and less energy consumption. Routing protocols can also be classified based on whether they are reactive or proactive. A proactive protocol sets up routing paths and states before there is a demand for routing traffic. Paths are maintained even there is no traffic flow at that time. In reactive routing protocol, routing actions are triggered when there is data to be sent and disseminated to other nodes. Here paths are setup on demand when queries are initiated.

WSNs usually consist of sensor nodes that sense the data and transport them to the sink node. The context for this work is a centrally administered, shared sensor network infrastructure, used concurrently by different applications for example, in a building where sensors are deployed in each room, and whose work is to sense the data such as temperature of the room, or light or acoustic monitoring conditions. This network is concurrently used for different applications, including one that monitors temperature in office and machine rooms, one that monitors light usage. In such sensor applications, the relative importance of sensor data streams often depends on the type and values of the data being sensed, and on how data from different sensor streams correlate with each other. Shared sensor network infrastructures therefore require a bandwidth allocation method, by which the nodes can decide how to allocate network bandwidth to sensor streams. The allocation method has to handle traffic that exhibits a high degree of spatial correlation, when a group of nodes in close proximity all detect an event of interest. It has to be able to change bandwidth allocations in the network depending on observed phenomena. The network lifetime of this scenario is increased by implementing the energy management of the sensors by introducing an algorithm called Geographic Adaptive Fidelity (GAF) algorithm.

The problem definition of this work is as follows: In this work, management of Bandwidth and Energy services of WSN along with reducing the congestion of the network, by implementing hop-by-hop flow control are proposed.

II. Related Work

This section covers the literature survey of the work of this paper.

In [1], the authors have carried out a survey of protocols and algorithms proposed thus far for the WSNs. They have tried to produce a better understanding of the current research issues in this emerging field of technology.

In [2], the authors have proposed a technique of managing the bandwidth by enforcing traffic class and traffic rules to data streams. The authors though have ignored the energy constraints of the nodes and focused solely on bandwidth management.

The authors in [3] have presented an algorithm called Geometric Adaptive Fidelity (GAF) that reduces the energy consumption in adhoc wireless networks. GAF conserves energy by identifying nodes that are equivalent from routing perspective and then turning off unnecessary nodes, keeping a constant level of routing fidelity.

In [4], the authors study a non-uniform grid based coordinated routing protocol along with network partition and energy consumption of the nodes in the network in a densely populated network area.

In [5], the authors provide a survey on the current state-of-the-art researches in the important area of bandwidth resource allocation and scheduling that has posed a challenging problem in wireless sensor networks. In this work, bandwidth reservation is considered in terms of time slot allocation in a pure TDMA or TDMA/CSMA based networks.

In [6], the authors have accomplished a thorough review of recent works on network protocols for wireless sensor networks along with their advantages and drawbacks, and also highlight of some guidelines in its improvement. The routing protocols such as LEACH (Low-Energy Adaptive Clustering Hierarchy), PEGASIS (Power-Efficient Gathering in Sensor Information Systems), SPIN (Sensor Protocols for Information via Negotiation) and GEAR (Geographical and Energy-Aware Routing) are surveyed.

Authors in [7] have applied data compression technique on sensor data to efficiently utilize the limited resources such as power supply, bandwidth for communication, processing speed, and memory space. Usually, processing data consumes much less power than transmitting data in wireless medium, so it is effective to apply data compression before transmitting data for reducing total power consumption by a sensor node.

In [8], authors propose an optimized bandwidth adaptation and utilization algorithm for real time applications in WSNs. The problem is formulated as linear programming (LP) together with specified constraints. Three types of applications (applications with strict delay requirements, applications with less stringent delay constraints and applications with delay tolerant capabilities) are considered for demonstration.

Authors in [9] have presented geographic multicast routing (GMR), a new multicast routing protocol for wireless sensor networks. It is a fully localized algorithm that efficiently delivers multicast data messages to multiple destinations. It does not require any type of flooding throughout the network. Each node propagating a multicast data message needs to select a subset of its neighbors as relay nodes towards destinations.

In [10], authors have addressed the coverage breach problem in wireless sensor networks with limited. In wireless sensor networks, sensor nodes are powered by batteries. To make efficient use of battery energy is critical to Sensor network lifetimes. When targets are redundantly covered by multiple sensors, especially in stochastically deployed sensor networks, it is possible to save battery energy by organizing sensors into mutually exclusive subsets and alternatively activating only one subset at any time.

In [11, 12], authors have plied the WSN technology in agricultural field and studied its environmental factors such as measuring temperature, humidity, controlling the water supply based on the moisture content of the soil.

Based on the literature surveyed above, the challenges of WSN such as management of bandwidth and energy, keeping the hop-by-hop flow control method for data transmission to reduce the congestion are selected

III. System Design

In this section, the emphasis is given on the explanation architecture of the system and the proposed solution of the work is defined.

A. *Proposed Solution*

The proposed protocol for this work where we a need to enforce rules to each data streams, keeping the constraints such as low consumption of energy and minimum congestion overhead can be solved by applying the combination of AODV routing protocol with GAF algorithm and choosing a hop-by-hop data flow control. The reason for using GAF algorithm in this work is simply that it reduces the overall consumption of energy of the nodes, increases reliability of the packets and also increases the network lifetime.

B. *System Architecture*

The system architecture given in fig. 1 consists of following modules:

Configuration: The user creates the network setup using this module. The network consists of the grid orientation of the sensor nodes in a 5×7 matrix model.

Rule Based BW Controller: Each Node in the wireless sensor network implements the Rule Based BW controller. After the configuration module, rules can be added into the system. Also the nodes apply the GAF algorithm so that the energy of the nodes does not drain out during the data transmission.

Hop by Hop Flow Controller: The packets passed out of previous control module are given to Hop by Hop flow controller to choose the next hop route and packet is delivered to the destination.

NS2 Output: The simulation script open the ns2 trace file and NAM output files. Using the trace files, Performance analysis can be done. Nam output file is used to show the output in neat GUI.

NAM Viewer: The NAM viewer is an application that projects the flow of simulation of the work. It is a GUI window where the user can observe the nodes and the data packet and hence can monitor the behavior of the work.

Tracer: In this module, the output trace file is generated that gives us the detailed analysis of this work in terms of statistics.

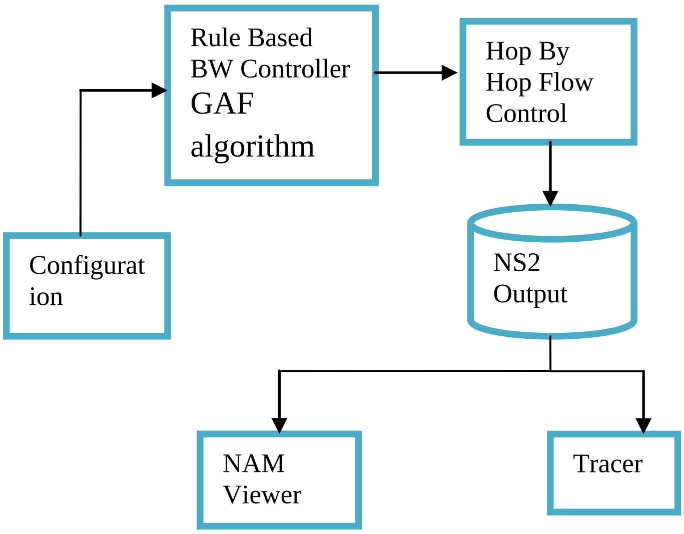

Fig.1 System Architecture

C. Rule System

Three different rules are proposed in this paper that specifies which type of data is to be treated in which manner by the network administrator or the application. A rule maps packets, whose payload includes a sensor data type and a value being reported, to a desired reception rate and a traffic class. Specifically, a rule is a function F that takes the sensor's data type, the value being reported, and other attributes (*e.g.*, sensor location, local node state corresponding to the stream, etc.) as input and produces a rate and traffic class.

F (type, value, attribute) → {rate, class}

The traffic class in a rule allows a network administrator as well as application writers to specify the relative importance of different data ranges for sensor streams. For example, one rule might specify that the temperature sensors provide an aggregate data rate of 4 packets/second, while a second more specific rule might specify that temperature sensors that report values above 80 degrees from certain locations do so at a higher data rate of 12 packets/second on a different traffic class that is treated at higher priority in the network.

D. GAF Algorithm

The GAF is an energy conserving algorithm where the nodes in a network form a virtual grid where all the nodes in that virtual grid square are equivalent with respect to forwarding packets. In GAF, nodes are either these three states: discovery state, active state or sleeping state

Initially, nodes start out in discovery state. In this state nodes turn on its radio and exchanges discovery messages to find out other nodes within the same grid. The discovery messages consist of a tuple of node_id, node_energy, and the threshold energy specified by the administrator.

When the nodes that take part in the data forwarding process are decided, the responsible node in each grid turns their state from discovery state to active state. The active node sets a timeout value to determine how long the node will stay in active state. After this timeout value, the node goes back to discovery state and recharges its battery.

A node when in discovery state or active state can change back to sleeping when it can determine some other equivalent node will handle routing. When transitioning to sleeping state node cancels all pending timers and powers down its radio.

E. Hop-by-Hop Flow Control

Any network with competing and dynamically varying traffic requires some form of congestion control to avoid high packet loss rates, long queues, or congestion-triggered collapse. On the Internet, congestion control is done end-to-end at the transport in transport protocols like TCP or in end system modules like the Congestion Manager [15]. End-to-end flow control schemes like TCP are not well-suited to our domain for the following reasons:

- End-to-end acknowledgment overhead: Many end-to end congestion control schemes require ACKs to be sent from the receiver, to allow the sender to obtain an accurate idea of the state of the network.
- Bad performance when windows are small: Protocols like TCP are notorious for poor performance when windows are small [14]. Although some recent solutions have been proposed for this problem [13], a fundamental problem is that small-window paths often tend to cause high packet loss rates in the way TCP adapts while probing for more bandwidth.

Our solution to this problem is to revive an old idea that is *hop-by-hop flow control* and adapt it to sensor networks. The idea in hop-by-hop flow control it that a congested node provides essentially immediate feedback to an upstream neighbor sending packets to it about the onset of congestion. By using the hop-by-hop scheme, the expectation is that once a packet is admitted into the system, it is generally not dropped due to congestion. Drops only occur due to data transmission errors or through explicit suppression by application-layer computation at nodes. This is a useful feature in wireless networks where network bandwidth is a scarce resource, and where it is wasteful to send packets only to have them dropped at later points on their path.

IV. Simulation Results

This section, the simulation parameters of the simulating environment where the work is to be implemented is mentioned, also the performance metrics that are used to measure the success of this work is explained. The simulator chosen to implement the above is NS-2.34 [24]. The results are compared with the existing protocols like AODV and DSR in the form of graphs.

Each simulation runs for 100 seconds and the values are taken as an average value of 3 simulation results. There are 35 nodes of which 3 are sensor access points (SAP) and one is the sink node.

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A. Simulation Parameters

Table 1. Simulation Parameters

Parameters	Values
Network Area	100 m × 100 m
Number of Nodes	35
MAC Layer	802.11
Routing	GAF-AODV
Message Packet Size	1500 bytes
Node Placement	Grid
Radio Range	40 m
IFQ Length	50 Packets

A. Simulation Performance Metrics

The performance metrics used to measure the simulation of the work are explained as follows:

- **Throughput:** Network throughput is the average rate of successful message delivery over a communication channel. This data may be delivered over a physical or logical link, or pass through a certain network node.
- **Packet Delivery Ratio (pdr):** It is defined by a factor of number of packets received by number of packets transmitted.
- **End-to-End Delay:** The time interval between the transmission of the packet by a source node and the reception at the destination.
- **Residual Energy:** Residual Energy is defined as the total amount of consumed energy of all the nodes in the network except for the sink node i.e. node 0.

B. Simulation Results

In this section, the graphical analysis of the work is done bases on the values obtained from the simulation environment. These graphs are plotted on the performance metrics described earlier.

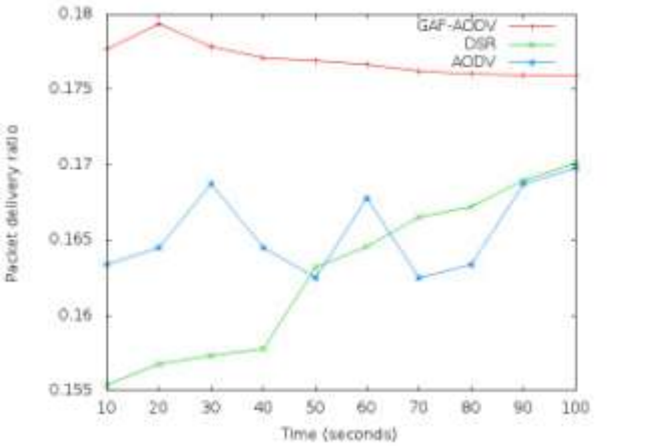

Fig. 2 pdr curves showing the comparison of proposed solution with the existing solutions.

The graph in fig.2 shows the comparison of the proposed system with the existing systems in pdr metric. As the curves show pdr of the proposed system is relatively higher than the existing systems.

In fig. 3, the delay of the proposed system is compared with the existing systems. This delay is measured as end-to-end delay of the packet arriving at the sink node. As the graph shows the delay experienced by the proposed system is relatively low when compared to the DSR implemented system, but is similar when compared to AODV implemented system. This is because AODV itself is regarded as a protocol which gives the users least amount of delay to send the packets to the destination.

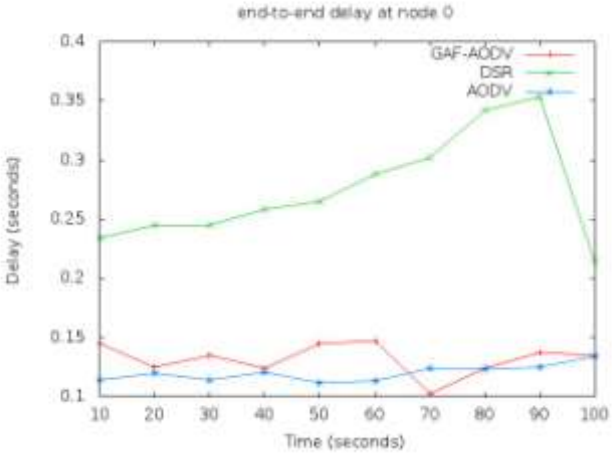

Fig. 3 showing the comparison of delay between the proposed system and the existing system.

In the figure 4, the comparison is done between the proposed system and the existing system based on the residual energy metric. As the graph shows the proposed system performs better than the other systems since neither of them has the GAF algorithm implemented in them.

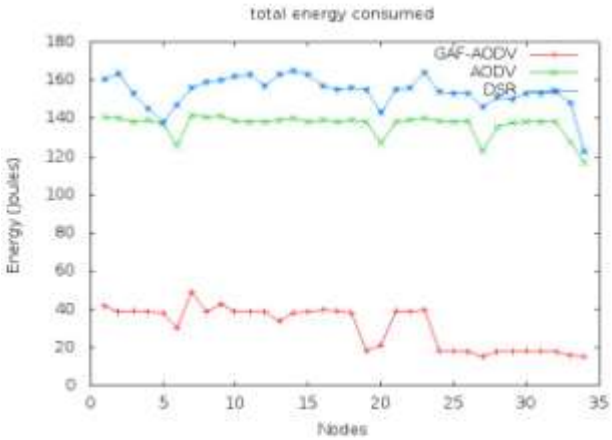

Fig. 4 showing the comparison of residual energy between existing systems and proposed systems.

V. CONCLUSION

The proposed system after the implementation of bandwidth management along with energy management successfully performs better than the system which does not employ any such management rules in the network. A simple rule-based approach to dynamically allocate bandwidth to sensor streams, a hop-by-hop flow control protocol to control congestion, and GAF algorithm to decide the nodes for forwarding based on sufficient amount of energy to successfully forward the packets are the three main mechanisms of the work. when events of interest occur, bandwidth needs to be shifted dynamically. It is believed that the rule-based system defined in this work provides an effective method to accomplish this in many cases

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