Single-path Streaming Optimized Routing Protocol for Dense Wireless Sensor Networks

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ABSTRACT

The Wireless Sensor Networks (WSNs) have advanced to the multimedia processing and streaming applications in the recent past with the advent of higher end motes like the iMote2. The data rates available from the radios of the WSN nodes are low so that for streaming applications to be sustained in these networks, special cares have to be taken to allow only one streaming path in any node's neighborhood, which means in a common sink network, all the protocol layers in the nodes are optimized for maintaining a single streaming path in the network at any point of time. In a dense WSN, for single path optimized streaming for maximum throughput, the MAC and routing layers have to be specially designed to avoid traffic generation from nodes in the vicinity of an ongoing streaming path. In this paper, a routing protocol is described which is built on top of a streaming MAC protocol called MLMAC. The Single-path Streaming Optimized Routing Protocol (SPSORP) establishes the routing table during the initialization phase of the protocol and suspends the route updates when streaming is detected in the vicinity of a node. The simulation in OMNeT++ simulator confirms the possibility of streaming in a dense WSN with the combination of MLMAC and SPSORD to the tune of compressed voice streaming rates with iMote2 hardware platform.

Keywords - Multihop Routing, QoS, real-time, Streaming, Wireless Multimedeia Sensor Networks, Wireless Sensor Networks.

Date of Submission : June 24, 2010 Date of Acceptance: August 05, 2010

I. INTRODUCTION

The WSN technology has graduated from applications involving low data rate random data collection to that do multimedia streaming over the last one decade of research both in hardware and software. Two main differences between WSN and other communication networks are the lack of standardization of the protocols and the severe constraints of resources like range, data rate, memory and processing power of the nodes. So far, the protocols developed for WSN are therefore suitable for certain kinds of applications on specific set of hardware. In this paper, a routing protocol for multihop streaming through a single path to a destination in a dense WSN deployment is proposed, that could be used in applications to stream voice from militant hideouts to a base station during anti-terrorist operations as described in [1]. In the modern societies plagued by terrorism, historic, religious and administrative buildings are vulnerable to occupation by militants for disrupting normalcy in governance. The counter-terrorist operations could be hampered by the lack of information from within the area of occupation and disruption in electricity and conventional communication systems in the location of interest. WSN can gather multi-media information in such situations with the help of nodes capable of signal processing and designed with streaming enabled protocols. The issues related to hardware and software for such a network is discussed in [1].

The streaming applications put constraints on any communication network and special efforts are required to guarantee the QoS during the streaming process. In a severely constrained WSN deployment, streaming application needs protocols optimized for maintaining a streaming path in all the layers of the network nodes. With the hardware presently available, multiple streaming paths to single base station from different sources would not be possible to be maintained simultaneously. The MLMAC[2] is a MAC protocol optimized for streaming in the WSN that has inherent features for gathering route information. The MLMAC is a synchronous protocol where every node synchronizes itself with respect to the BS. The node that hears control packet broadcast from the BS forms a tier-1 node. The node that hears control packet broadcast from a tier-1 node forms a tier-2 node and so on. In this way, a node which is in communication range of any other node having connectivity to BS will be part of a tier and the tier number of the node indicates its distance to the BS. The next hop node to BS can be obtained from the control packet broadcast which is a feature of the MAC layer. This feature is utilized in the proposed routing protocol to set up a multihop path towards the base station from a source node for streaming applications in a dense WSN. The routing protocol and the MAC protocol adapt themselves to optimize the throughput in the streaming path by reducing the control packet transmissions in the neighborhood when the streaming is on.

Streaming applications in WSN have been described in [1][3][4]. In [1], an important infrastructure that needs to be protected against occupation by antisocial elements for ransom could be either pre-deployed (as per planning due to its vulnerability) or temporarily deployed (by shelling) with suitable sensor nodes. The area between the infrastructure and control room where base station is located can be deployed with routing nodes randomly. The sensing nodes can gather information from the infrastructure as and when required and send it to the base station by multi-hop routing even if all other communication means are cutoff from the area. A wireless sensor network for voice streaming across a large area in an operational coal mine using FireFly nodes is described in [3]. FireFly is a platform to support 2-way audio streaming concurrently with sensing tasks. Such applications require relatively high bandwidth utilization, impose severe constraints on the end-to-end delay and require tight coordination between sensor nodes. The hardware is designed for tight time synchronization required for a TDMA-based media access protocol. There is a real-time operating system for sensor nodes and packet scheduling for streaming voice across multiple hops. The network provides two-way communication for trapped miners when there is an infrastructure failure. However, the entire network is pre-installed and is capable of only voice streaming. In [4], energy efficient and high quality video transmission architecture is proposed for WSN in which the application, transport and network layers are optimized for video transmission. The routing protocol presented in this architecture forwards packets using a hierarchical topology and an adaptive single-path transmission. The hierarchical topology to maintain a single-path streaming route is the central theme of our protocol.

There are QoS based routing protocols proposed for WSN; the QoS parameters considered being delay, energy, bandwidth etc., when delivering data to the BS. Sequential Assignment Routing (SAR) proposed in [5] is one of the first routing protocols for WSNs that introduces the QoS based routing decisions. It is a table-driven multi-path protocol that aims to achieve energy efficiency and fault tolerance. The protocol ensures fault tolerance and easy recovery, but suffers from the overhead of maintaining the tables and states at each sensor node especially when the network is dense. SPEED [6] is a routing protocol for WSN that provides soft real-time end-to-end guarantees. The delay estimation is done from a node to each of its neighbors. The node selects the node which meets the speed requirement while routing decision is to be taken. The protocol is processing intensive and must store delay metrics for every node. For a fixed destination routing, our protocol is simple and optimized for throughput and delay. A routing enhanced duty-cycle MAC protocol is described in [7]. In this protocol, a control frame sets up the schedule for relaying nodes for energy efficient packet delivery and also moves the contention traffic away from the busy area. These features are adopted in our protocol for setting up a streaming path from source to the base station and reduce the traffic generation around the streaming path in a dense network thereby optimizing the throughput while streaming. In [8], to get more bandwidth, a multi-path routing with reduced inter path interference is proposed. Interference awareness and energy saving are achieved by switching a subset of sensor nodes in a passive state in which they do not take part in the routing protocol. This concept of suspending route updates in the interference range is adopted in our protocol.

The section II of the paper describes the routing protocol. The results are analyzed in section III. Section IV concludes the paper and describes the future work.

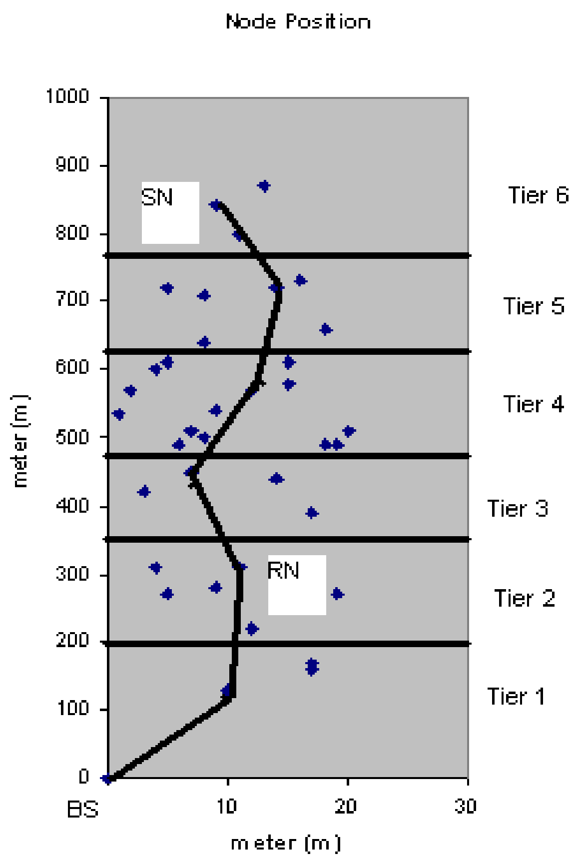

Fig. 1 Nodes and tierNum as distance to BS
(SN = Sensing Node, RN = Routing Node and BS = Base Station).

II. PROTOCOL

The MLMAC protocol segments the nodes in a WSN field to tiers as shown in Fig.1. The base station (BS) is the only node in tier 0 and every node records its tier number in its MAC layer. The tier number of a node represents the number of hops to the BS from that node. The tier number forms part of the MAC frame and the tier number of a received MAC frame indicates its shortest possible distance to the BS. This information can be utilized in maintaining a routing table to the BS in every node. A node has to check for bidirectional nature of the link as it is needed to set up and maintain a streaming path. The routing algorithm is as shown in Fig.2.

```
Algorithm
if (setup phase)
  if ( No route to BS from the node)
     Received route broadcast from Tier Number N
     if (my tier number > N)
        Send route request to source in tier number N
        if (ack received)
           Enter route to BS in routing table and
           mark the node state as "route to BS" exists
           Broadcast "route to BS"
        else (try n times)
    if (Route to BS exists)
      ignore the broadcast
if (not in setup phase)
  if (in streaming path)
    suspend route broadcasts
  if (not in streaming path)
    if (route to BS exists)
      broadcast route to BS periodically
    if (received route broadcast from node in
        its routing table entry)
       set a timer
    if (timer expired)
      Indicate route to BS does not exist
      suspend route broadcast
   if (packet received for BS from upstream node)
     source address entered in routing table as route
     to tier number N+1
   if (packet received from tier N-1)
     send it to nodes in routes for tier N+1
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Fig. 2 Routing algorithm

In the set up phase of the nodes, the MAC layer calculates the tier number of the node from the control packets broadcast from lower tier nodes. The MAC layer forwards the address of this lower tier node from where the control packet was heard and own tier number to the routing layer. The routing layer will check the connectivity to that lower tier node to validate a bidirectional link to the BS. Once the link acknowledgement is reached, the routing table is updated with a "route to BS" and mark the node as having a "route to BS" to participate in the route broadcasts in its slots. This route broadcasts done periodically are part of the route maintenance procedure and would be listened to for checking the validity of the routing table entry by every node. As long as a "route to BS" has been available in its routing table, the node further ignores the route broadcasts from the lower tier nodes.

After the set up phase, the node listens to route broadcast from the next hop node to BS in it routing table and set a timer for the route to BS entry. Before the expiry of the timer if a route broadcast was not received from this node, the state of the node is changed to having "no route to BS" and it stops broadcasting "route to BS" in its slot. Further, on hearing a route broadcast from a lower tier node, the node can get a "route to BS" after checking for bidirectional nature of the link between these nodes. A node keeps one "route to BS" based on the shortest route calculated as per its tier number. In case the tier number changes or the existing route fails, the node broadcasts a route request. A node receiving a route request broadcast from a tier above it, would send a route acknowledgement to the sender. Sending node updates its "route to BS" with the address of this node.

When a packet is received from an upstream node (tier number N+1), to be forwarded to the BS, a routing table entry is made for tier number N+1 with the source address of this packet. When a packet is received from a lower tier node (tier number N-1), with destination address being any node in the higher tiers, the packet would be forwarded to all the next hop nodes for tier number N+1 in the routing table. Once a node becomes part of the streaming path, route broadcast would be suspended so that data packets would flow at regular time intervals from the node. During streaming, an intermediate routing node would keep the route to the source and destination node in its routing table. The source address of the packet towards BS is recorded in the routing table with upstream routes for setting up of the streaming path. The route to tier above is required when sending queries from BS to an upper tier node while setting up streaming path or during streaming. The routing table is as per the following format shown in Table 1.

Table 1: Routing Table

Destination	Next Hop Address
BS	N_1
Tier N+1	X_1
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Tier N+1	X_n

III. SIMULATION RESULTS AND ANALYSIS

The Mobility Framework[9] in OMNeT++4.0[10] simulator is used for the simulation of the protocol. 40 nodes were randomly deployed in an area of 100m x 1500m. The nodes in each tier along with the tier number are shown in Fig.3. The hosts were having a constant data rate application layer (SensorApplLayer in Mobility Framework) with one of the nodes in tier number 11 selected to generate packets that are representative of compressed voice generated at the rate of 16 kbps. The radio was set to be operating on 2.45GHz at a data rate of 250 Kbps. The CC2420 radio available for WSN nodes has the above parameters. The MLMAC layer and fixed mobility model were used in the hosts of the network along with simple physical layer model in the mobility framework. The simulation was run for 1000 seconds to generated 1000 packets at a rate of 12.5 packets per second with the application scheduled to start the data generation after 500 seconds having each packet of 100 bytes. The route was set up from node in tier 11 to the BS in 11 hops with the route setup delay of nodes in each tier shown in Fig.4. The route setup delay is related to the tier number of the node as the route broadcast from a lower tier node starts only after it has established a route to BS. Therefore, the route setup procedure ripples through the lower tier nodes to higher tier nodes. The average route setup delay per hop was found to be 0.78 seconds.

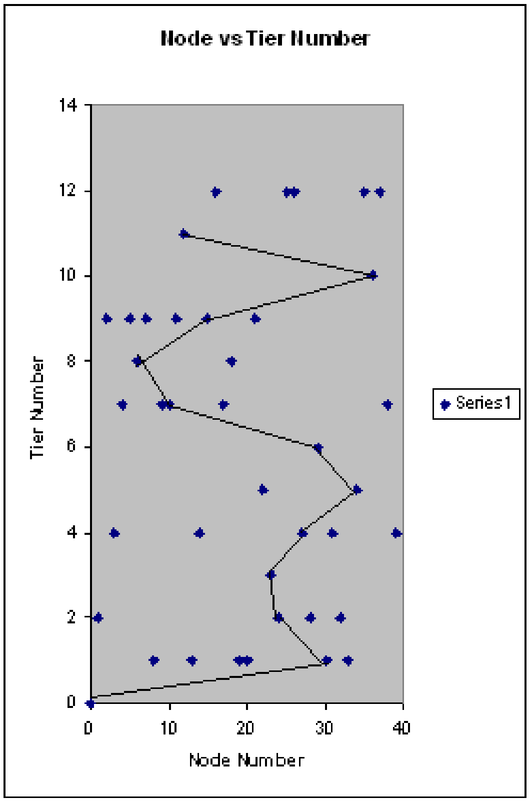

Fig. 3 Node number vs tier number

The minimum average setup delay for a node in tier 1 is 0.28s which is two frame times in the simulation. The minimum delay noticed is 0.23s. Since only one node can get a route request acknowledgement in a frame time, other nodes will have varying amounts of setup delay in the same node. Higher tier nodes will have added setup delay based on the setup delay of lower tier node which is its next hop node to BS. This fact can be seen from the simulation results shown in Fig.4.

The route setup activity happens during the idle phase of the network much before the streaming application starts. Once the streaming is noticed, the route setup in the participating nodes are suspended and also since the MLMAC layer does not transmit if it finds streaming in the vicinity, the route broadcast will not proceed in the neighborhood of the streaming path. Hence the routing protocol is optimized for streaming applications.

IV. CONCLUSIONS AND FUTURE WORK

Streaming applications in WSN need customized protocols to optimize the available throughput from the low data rate radios. The routing and MAC layers are of paramount importance in achieving the optimum throughput in the network. A routing protocol optimized for streaming is designed over the MLMAC protocol which is also a streaming optimized MAC protocol.

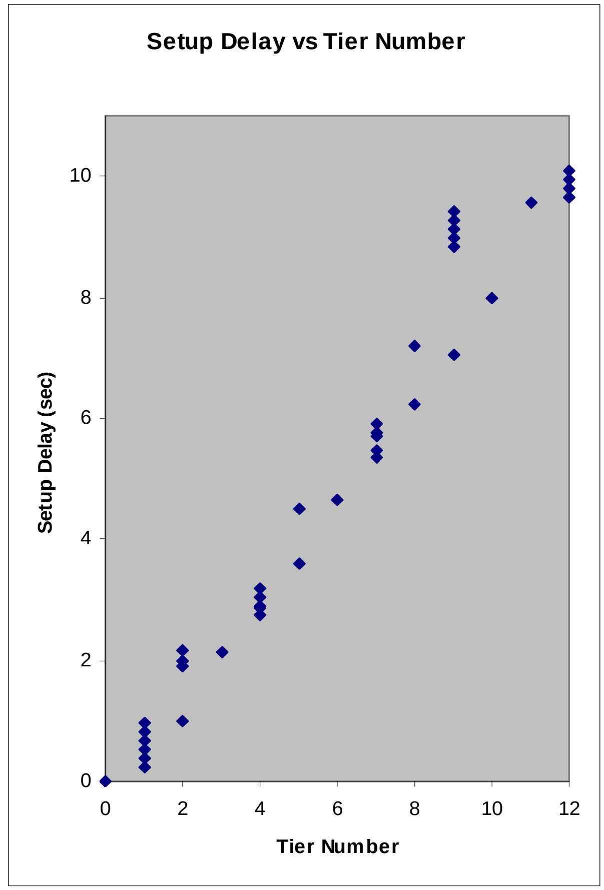

Fig. 4 Tier number vs. Setup delay

In voice streaming applications, the nodes in the multihop streaming path have to transmit and receive packets at a constant rate depending on the compression rate. The constraints of WSN nodes demands techniques to avoid traffic around the streaming nodes. In this protocol, the streaming nodes suspend the route updates. The underlying MAC layer detects streaming in the neighborhood and suspends the transmission; hence the data rate in the network for streaming is optimized. The protocol has been simulated in OMNeT++4.0 simulator and the results validate the possibility of voice streaming in WSN with nodes of the iMote2 [11] variety having CC2420 radio.

The simulation model has not included an explicit battery model to account for energy constraints of the WSN nodes. Also, the propagation model used is simple and other statistical models need to be used in future simulations. Finally, the protocol has to be tested on real platforms like the iMote2 nodes, porting the protocol in NesC for TinyOS.

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Authors Biography

Mr Sudheer Kumar N.V received his B.Tech from Government Engineering College, Thrissur, Kerala in ECE and M.Tech in Electrical Engineering from IIT Kanpur. He has worked in the Design and Engineering department of BEL Pune and had a stint in Doordarshan as Assistant Station Engineer prior to taking up the teaching profession. Presently he is working as Assistant Professor at Military College of Telecommunication Engineering, Mhow, Madhyapradesh. He is pursuing his PhD in the field of Wireless Sensor Networks at Devi Ahilya Viswa Vidyalaya, Indore, Madhyapradesh. He has published papers in national conferences and international journals. His research interests include communication protocols, mobile Adhoc networks, mobile communication and coding theory.

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