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Multi-Hop Routing Algorithm For Delay Reduction And Lifetime Maximization In Wireless Sensor Networks

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Abstract

Wireless sensor network has become a necessity than luxury in common man's life. A new routing protocol by name Chain Routing for Convergecast Small Scale (CRCSS) wireless sensor networks is proposed in this paper. The set of sensor nodes send the data sensed periodically to the base station located in the area of interest. The nodes that fail to send the data to the sink node in one hop send the data to one of the neighbors so that they can forward the data to the base station. The proposed protocol is energy efficient and faster when applied to small scale sensor networks. The impact of network radius on energy per packet and average number of hops is studied. The effect of various degrees of asymmetry in the network on latency and energy per packet are plotted in comparison with existing algorithms.

Keywords: *Communication System, Convergecast Routing, Energy, Latency, Multi-hop Networks.*

1. Introduction

The emergence of low-cost low-power radios, along with the recent advancements in research on wireless communication and network control, has enabled the deployment of wireless sensor networks for many application including communication, process monitoring and control. Sensors together form a network to accomplish communication among themselves. Because of the limited transmission range of sensors multi-hop routes can also be formed to connect source and destination pairs. The sensing and information transmission can be periodical or event based. A wireless sensor network consists of sensors implanted in an environment for collecting and transmitting data regarding changes in the environment based on the requests from a controlling device called base station using wireless communication. Wireless sensor networks are being used in medical, military, industrial, consumer electronics and environment monitoring applications.

A wireless sensor normally consists of a processor unit, limited memory unit, a power unit, sensing unit and transceiver units. Additionally, a sensor can have location finding system, mobilizer to enable the movement of sensors and a power generator which are application dependent sub-units. The size and weight of a sensor restricts the processing capability, amount of memory and the amount of power that it can store. A major part of power consumed by a sensor is used to run the transceiver circuitry that is performing the receiving and transmitting of information to other sensor nodes in the network. As, the transmission range of a sensor increases, the power consumed by the transceiver also increases.

In a network, broadcast - dissemination of information from a central node and convergecast - gathering of information towards a central node, are important communication paradigms across all application domains. A convergecast routing is usually preceded by a broadcast, or both can occur in an interleaved manner. An example of this communication pattern is the environment monitoring application in which sensors embedded near the area of interest collect and send data to an external monitoring station in response to a query by the monitoring station. Collisions occur in a wireless network when multiple nodes simultaneously transmit to the same node over the same channel or a receiver is in the transmission range of another communication taking place over the same channel. Such collisions waste resources like bandwidth and energy as well as increase data latency and hence they are undesirable. For broadcast and convergecast to work in a collision-free manner, time division multiplexing can be used. That is to allocate a schedule that specifies for each node in the network the time-slots in which it will receive data from other nodes and the time-slot in which it will send data to other node. This schedule is assigned for a particular duration of time and it gets repeated for each such time duration.

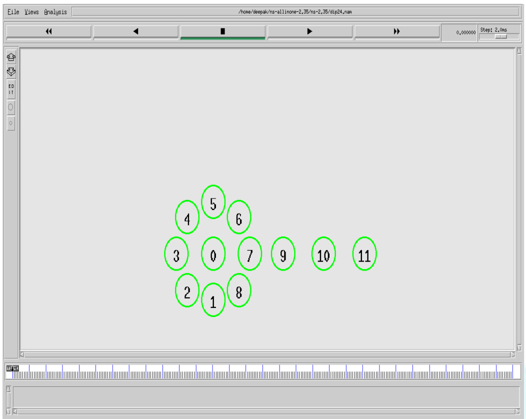

Fig. 1 : Network topology with 12 nodes.

A network of 12 sensor nodes numbered from 0 to 11 is set up as shown in Fig. 1. Node 0 is the destination node and all other nodes around node 0 transmit the sensed information to node 0. The spacing between the chain of nodes, *d* is varied to analyze the number of hops the information has to pass through. The operation is shown to be efficient when *d* is small and there are fewer hops between the source and the sink. The average number of hops, the data delivery rate, and the average energy consumption for nodes 1-8, and for nodes 9, 10, and 11 separately are plotted.

2. Literature Survey

Following is the discussion of some of the papers related to wireless sensor routing and convergecast routing.

Shang *et al.,* [1] study the problem of finding the schedule for transmitting the data collected from sensors to the sink in a convergecast wireless sensor network, in a minimal time. An approximation algorithm for data collection and transmission is proposed. Yen *et al.,* [2] schedule the beacon messages in a tree-based Zigbee network to reuse the beacon slots used by the neighbour nodes. The reuse of beacon slots reduces the beacon collisions and also packe delivery latency. If the risk of reusing beacon slot is high, then reuse is disallowed. The implemented simulation results show that the proposed algorithm is better than conventional methods.

Zhang *et al.,* [3] propose a coordinated convergecast framework for achieving high convergecast reliability in wireless sensor networks. The tradeoffs among reliability, latency, and throughput of the network are analyzed. The authors integrate aggregation for efficiency and duplication for high reliability. Optimal scheduling for achieving maximum throughput in convergecast network is considered as future work. Tsai and Chen [4] propose a novel conflict-free convergecast scheduling method called Minimal Time and Conflict-Free convergecast schedule (MTCFCS) to minimize the collecting time in a wireless sensor network. A tree with sink as the root node is constructed for collection of data from a sensor network. Time division multiple access scheduling is used to solve collision problem in transmission in the network.

Kam and Schurgers [5] propose a combined MAC and routing protocol ConverSS that uses contention-free MAC in conjunction with beaconing and overhearing in small scale convergecast wireless sensor networks. The protocol is optimized to handle single-hop networks, but, has the ability to route a packet through multiple hops, when necessary. An improvement of a factor of 10 is observed by ConverSS routing protocol, as compared to ideal protocol for small scale wireless sensor networks. Annamalai *et al.,* [6] introduce a heuristic Convergecasting Tree Construction and Channel Allocation Algorithm (CTCCAA) that constructs a tree with schedules assigned to nodes for collision free convergecasting. The algorithm minimizes the total duration for convergecasting using tree and shows that the same tree can be used for broadcasting that will be as efficient as tree broadcasting.

Pan and Tseng [7] introduce Minimum Delay Beacon Scheduling (MDBS) problem for quick convergecast that is compliant to Zigbee standard for tree-based wireless sensor networks. The results are optimal solutions for special cases and heuristic algorithms for general cases. Simulation results show that quick convergecast is achieved by using the proposed algorithms. Considering asynchronous sleep scheduling to support energy-efficient convergecast is the possible extension to this work. Haibo *et al.,* [8] address the joint link scheduling and channel assignment problem for convergecast in networks operating according to the WirelessHART standard. Hongwei *et al.,* [9] discuss challenges of bursty convergecast in multi-hop wireless sensor networks and design Reliable Bursty Convergecast (RBC) to address the channel utilization and packet retransmission. RBC is compared to implicit-ack scheme via experiments to show that RBC doubles the packet delivery ratio and reduces end-to-end delay.

Tian *et al.,* [10] propose a Stateless Protocol for Real-Time Communication in Sensor Networks SPEED, that provides three types of real-time communication services, *viz,* real-time unicast, real-time area-multicast and real-time area-anycast. SPEED is a stateless, localized algorithm with minimal control overhead. The combination of MAC and network layer adaptation is used to reduce end-to-end delay and provides good response to congestion and voids. SPEED is compared with DSR, AODV, GR, SPEED-S and SPEED-T protocols to show better performance with respect to delivery ratio, energy consumption and end-to-end delay. Upadhyayula *et al.,* [11] show that using the same tree for broadcast and convergecast is an inefficient approach in terms of latency and energy consumption and propose an algorithm which constructs a tree using greedy approach where new nodes are added to the tree such that weight on the branch to which it is added is less. Compared to tree based convergecast and tree based broadcasting, ConvergeCast Algorithm (CCA) implemented in this paper consumes less energy and exhibits low latency.

Tomas *et al.,* [12] consider the problem of building forwarding tree for multicast and convergecast traffic in short-range wireless sensor networks and propose a Localized Area-Spanning Tree (LAST) protocol. LAST protocol guarantees strong connectivity among the nodes of the network optimizing the energy cost and interference imposed by the structure. Fabrice [13] propose C-MAC protocol for multi-hop convergecast wireless network that selects a sub-tree of the shortest paths to the sink containing exactly k leaves to forward maximum of the traffic towards the sink. C-MAC is based on CSMA-CA like approaches and assigns priorities to the k-tree core nodes to avoid collisions among themselves to increase the throughput compared to original IEEE 802.11 protocols. Advantage of this protocol is that it does not require any synchronization mechanism among the sensor nodes in the network.

3. Background

ConverSS [5] is a routing protocol specifically for small wireless sensor networks where most nodes are one hop away from the sink, and already established routes are reused. For many of the real-time sensing applications require sensor generated data to be sent to the sink periodically in their sending slots. As the number of nodes is small and fixed at the time of network initialization, Time Division Multiple Access Medium Access Control (TDMA MAC) is used for communication between the nodes. ConverSS operates in two phases, phase 1 considers the nodes that are one hop from the sink, so each node attempts to send information directly to the sink in its sending slot. Each node sends the data it has to the base station and then goes to sleep mode by switching off their radio units to save energy. The sink broadcasts a delivery status message to acknowledge the receipt of data at the sink.

The nodes that do not receive delivery status message sent from the sink enter phase 2. At the end of Phase 1, packets from all 1-hop neighbours of sink node would have sent their data to the sink. In Phase 2, any nodes whose packets were not delivered to the sink perform a controlled flooding of data packets, in which nodes broadcast their data and receiving nodes rebroadcast the same to deliver it to the sink. Flooding does not require a handshake, thus justifying the use of asymmetric links in routing the data to the sink where quality of link is not the same in both the directions. Given the small number of nodes, the two-phase sending interval is typically short enough such that the network topology will be stable during that time. The two phase system results in more of waiting of the sensor nodes that have already sent the packet to the sink node. The reduction of this waiting time results in better network lifetime. The proposed routing algorithm attains these results and is better than the existing two phase algorithm.

4. Implementation

A network consisting of 12 nodes deployed in fixed locations and another network of 50 sensor nodes randomly deployed are considered for implementation. One network without link errors and one with varying degrees of link errors are considered for analyzing various parameters. Every sensor node in the network has a sending interval for sending the information they have sensed to the base station. The nodes wakeup at the beginning of the sending interval and transmit the data sensed. Each node is given a time frame or slot to send its data and the nodes transmit there packet in sequence, so that if a node is not able to send the data directly to the sink, the nodes that have already transmitted to the base station can be used for route formation. Normally routing of information from one node to another node is done with the help of routing table. By using the route reuse concept the use of routing table is avoided for small scale networks.

The transmission procedure is as follows. The current time is verified, and if the current time is less than the phase end time the node sends the packet. Before sending the packets the node that is in the current sending slot checks the distance between itself and the sink. If the distance is less than the transmission range of sensor nodes in the network then the node sends the packet directly to the sink and considers the sink as its parent. If the distance is more than the transmission range, then the node finds the nodes that are already participated in routing. If more than one neighbour satisfy this condition then the node that is closer to the sink is chosen and it is considered as the parent of source node. Further packets are sent through the parent to the sink. Once all the sensor nodes have sent the packets to the base station the nodes in the network go to sleep till the next interval. The duration of the transmission phase is such that all the sensor nodes have successfully transmitted their data to the sink successfully. As the network is small in size, the possibility of packet loss or packet collision is less and the same fact is verified by simulation results where 100 % packet delivery factor is achieved.

The proposed algorithm Chain Routing for Convergecast Small Scale (CRCSS) wireless sensor networks to find the chain of shortest path from every sensor node in the network to the sink is given in Table 1. Wireless sensor network with sink and other sensor node positions is given as input to the algorithm. In each sending slot the sensor node has to send the data to the sink node. If it does not have any data to send to the sink the source node goes to sleep till the next sensing slot. If the sensor node has data to send to the sink, the sensor node finds the distance between itself and the sink node. If this distance is within the transmission range of sensor node then the packet can reach the sink in one hop and the sink becomes the parent of the sensor node. The delivery status bit of that sensor node is set to 1 to indicate that this node has sent the packet to the sink and it can be a forwarding node.

Table 1. Algorithm CRCSS: Chain Routing for Convergecast Small Scale Wireless Sensor Networks.

```
Input: Wireless sensor network with sink and
       sensor node positions.
Output: Chain of links from each of sensor node to
       the sink.

for all the sending slots do
  wake up at the start of sending slot
  if current time <  end of sending slot then
    for all the sensor nodes in the network do
      if dist(node, sink )  <= trans_range then
        send packet to sink
        set the delivery bit
        add sink as parent
      else
        call find_forwarding_node(node)
          route the packet through the
              forwarding node.
          add the forwarding node as parent
      endif
    endfor
  else
       sleep until the next sending interval
  endif
endfor
```

Table 2. Algorithm Find_forwarding_node

```
Input: source node that sends packet
Output : forwarding node to reach the base
station

find the neighbor whose delivery bit is set
    if more than one such node exists then
      for each neighbor node
          find distance between them and sink
      endfor
       choose the node neighbor closer to sink as
              forwarding node.
      endif
return forwarding_node
```

If the distance between the sensor node and the sink is more than transmission range of the sensor node, then the sensor node has to find a node to forward its data to the sink. Table 2 gives the algorithm to find suitable forwarding node to route the packet to the sink node. The sensor node lists the neighbours whose delivery status bit is 1. If only one neighbour exits whose delivery status bit is 1, then it is chosen as the forwarding node. If more than one such nodes exits, the algorithm selects among the neighbours the node closer to the sink. The forwarding node becomes the parent of the sending node. Choosing the forwarding node continues till the sink becomes the parent of all the sensor nodes.

After the completion of the algorithm the shortest path from sensor nodes to sink is defined and the packets are routed in these paths for all the sending slots of simulation. The sensor nodes deployed in the network except the sink node are homogeneous nodes and transmission range of each node is fixed at 100 meters. The sink node has to be active always and is provided with infinite energy and transmission distance theoretically.

The Chain Routing for Convergecast Small Scale Wireless Sensor Networks is a combined MAC and routing solution for reliable and energy-efficient convergecast for small-scale wireless sensor networks. CRCSS is designed specifically for cases where most nodes are one hop away from the sink, and where there is an opportunity for reusing establishing routes. For many of these real-time sensing applications, sensor generated data must be sent to a sink periodically. As these are small networks, it is feasible to use a fixed-assignment

TDMA MAC, in which each node is assigned a dedicated time slot for sending. The number of nodes in the network is fixed at the system initialization. However, this setup is sufficient for most sensing missions, which have a small, consistent team of sensor nodes.

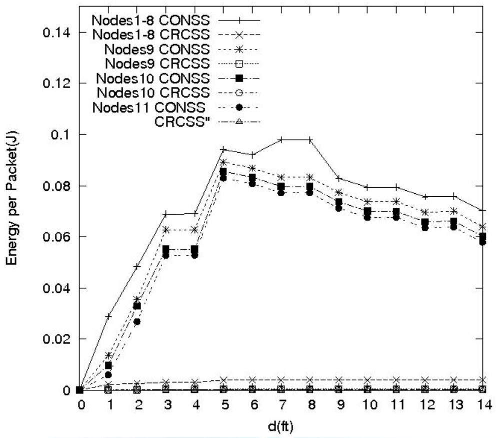

Fig. 2. Distance between Nodes versus Energy per Packet

4. Performance Analysis

To evaluate the performance, the CRCSS protocol is implemented using NS-2 simulator.

A network of 12 nodes placed as shown in Fig. 1 is considered to analyze the effect of distance between nodes on energy per packet and number of distance of *d* ft and are one hop away from the destination node. Nodes 9, 10 and 11 are at a distance of 2 *d*, 3 *d* and 4 *d* from node 0 respectively. Fig. 2 shows the values of energy per packet as the value of *d* varies from 1 ft to 14 ft, is plotted in the graph. The transmission range of the node is fixed to 9 ft. By varying the value of d, energy spent per packet by the sensor nodes and number of hops required to reach the base station are noted and plotted in the graphs. Fig. 3 is the graph of number of hops versus values of distance

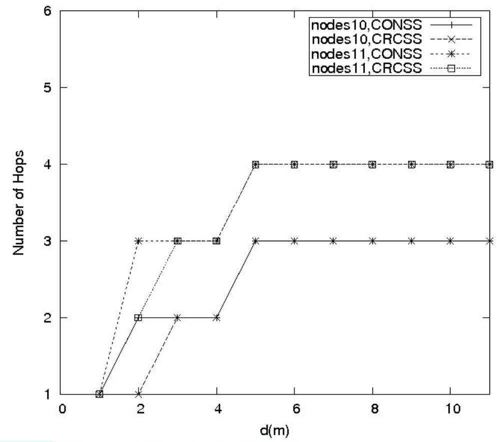

Fig. 3. Distance between Nodes versus Number of Hops

d varied from 1 ft to 12 ft. Number of hops to reach base station from nodes 1 to 8 is not shown in the graph because it remains one hop only. When nodes are in range of the base station, both the protocol functions primarily as a MAC, and the energy consumption is very efficient. When some nodes are out of range, other nodes must accommodate the need for routing, and thus ConverSS consume more energy than CRCSS, thus CRCSS out performs ConverSS as the number of hops increases.

For 50 sensor nodes deployed the network area radius is varied from 100 m to 160 m to analyze the number of hops to reach the destination node from other nodes. The average number of hops and maximum number of hops to reach the destination from the source nodes as plotted in Fig. 4. For 150 nodes maximum number of hops is 8 where as average number of hops is only around 2.

Table 3. Values of Average Energy Spent per Packet without Asymmetry

Number of nodes	ConverSS	CRCSS	Percentage improvement
5	0.00248146	0.00248146	---
10	0.00243122	0.00243122	---
15	0.00241627	0.00241627	---
20	0.0024513	0.0024513	---
25	0.00244215	0.00244215	---
30	0.0102601	0.00287458	71.98 %
35	0.019394	0.00314455	83.78 %
40	0.0261874	0.00342831	86.90 %
45	0.0983324	0.0037212	96.21 %
50	0.20557	0.0039598	98.07 %

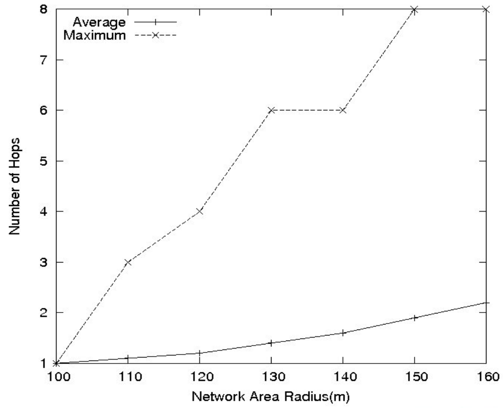

Fig. 4: Network Area Radius versus Number of Hops.

Fig. 5 exhibits the reduction in number of hops in reaching the base station from different source nodes when number of nodes is increased up to 50 nodes. Up to 40 nodes we see that both the protocols give the same results because most of the nodes are one hop away from the base station. But after that there is a slight lesser number of hops required to reach the base station from the source nodes in the case of CRCSS protocol.

The network of 50 sensor nodes with varying erroneous links is considered for analyzing energy spent per packet and latency per packet. The percentage of erroneous links in the network is considered as 0, 12 and 23 %. Fig. 6 shows that as the percentage of erroneous links increases the energy spent per packet in the network also increases as more number of nodes in the network transmit the sensed information to the base station. Similarly the latency in the delivery of packet from different sensor nodes to the base station also increases as shown in Fig 7.

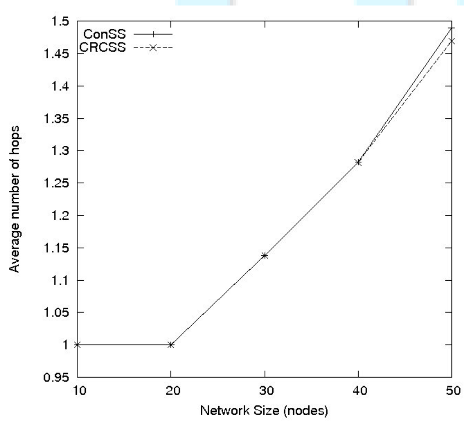

Fig. 5 : Network Size versus Average Number of Hops.

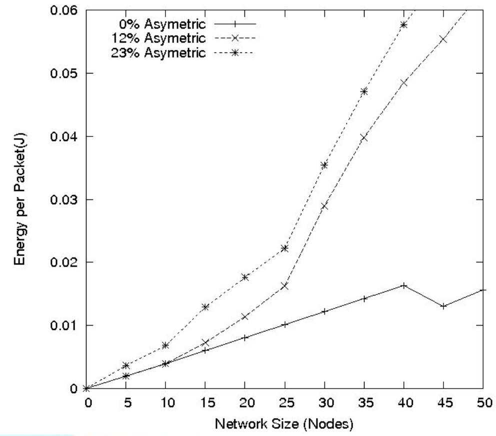

Fig. 6 : Network Size versus Energy spent per Packet for Different Symmetry.

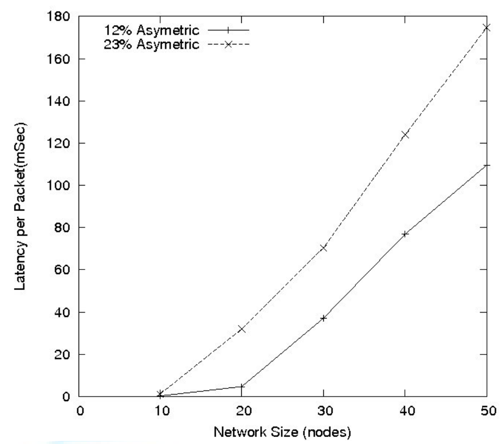

Fig. 7. Network Size versus Latency per Packet.

5. Conclusion

The proposed CRCSS protocol for wireless sensor networks protocol consumes less energy when compared to ConverSS as the network size grows beyond 25 nodes. For more than 25 nodes the network topology changes to multihop network, below which all the nodes are in one hop range from the sink. The average latency of CRCSS is comparatively less than ConverSS when the nodes are in multihop range. CRCSS is capable of handing routing for large network where many of the nodes are in multihop range from the sink, more efficiently than ConverSS. CRCSS is equipped to handle all type of network setup but ConverSS fails due to the inefficiency of flooding when nodes get stretched out to have longer routes. The simulation illustrates that ConverSS is not meant as a generic solution for all types of networks and CRCSS performs relatively good.

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