Dynamic Survivable Path Routing for Fast Changing IoT Netwok Topologies

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***Abstract*—IoT is the main enabling factor of the promising future communication networks. Several identification and tracking technologies, wireless sensor and actuator networks, distributed intelligence and other enhanced communication techniques are put together to establish IoT framework. Communication protocols and routing strategies in these mesh-like sensor networks should be carefully designed to cope up with the fast changing nature of the topology. This paper tries to propose a protocol in the real time network where the traffic is more and also congested by so many data sources sending their packets to the base station at the same time. The protocol selects the path with a high survivability factor at the same time it should try to select the one which has less interference from the other nodes as well as the environment. For selecting the next hop node, our algorithm uses a criterion which is a function of the signal-to-interference-noise-ratio of the link between those two, survivability factor of the path from that node to the destination, and the path loss distance from that node to the destination.**

***Keywords*-IoT; WSN; Network Survivability; Path Survivability Factor; Signal to Interference and Noise Ratio; path loss distance to Sink.**

I. Introduction

Internet of Things (IoT) becomes an inevitable technology in the field of future communication networks [1]. It collects data from different objects and their surroundings, analyzes the collected information and provides services for various applications. It uses distributed computing and analyzing technologies and cloud based architectures to provide intelligent service [2]. For collecting the information from the surroundings, IoT employs Wireless Sensor Networks (WSN). The sensor networks are composed of low power devises with restricted computing and communication capabilities. These IoT sensor networks are mainly in the form of mesh topologies. These mesh networks are highly dynamic in nature with fast changing topology structure and node characteristics. There are various routing schemes in sensor networks that utilize the available restricted resources at sensor nodes more efficient manner. The techniques for IoT based networks should consider dynamic nature of the nodes for their routing selection. Since the network structure, signal strength and interference, the exact path loss distance to the neighboring hop etc. are need to be considered for efficient communication structure. There are some energy aware cloud computing model for green computing that trying to solve energy waste problem in dynamic network environments [3]. Network survivability is another metric that is more useful for improving the performance of the routing protocol [4]. That is, the protocol should make sure that, the connectivity is maintained as far as possible in a network, and the energy level of the whole network would be in an almost equal range. This is a situation which is opposed to the energy optimization protocols which will find the optimal paths between source and destination and then decrease the nodes energy along that path, leave the topology with wide difference in the energy health of the sensors. Eventually, it leads to the situation that the network is disconnected into subnets. If the power level of nodes in the network burns comparably, then the sensors located at the center of the network will be continuing for providing the connectivity for an extended duration of time, and the delay to get the network partitioned increases. This will lead to the situation that the network degrades more gracefully which is the idea of network survivability [5]. So through our work we are trying to design an energy efficient survivable path routing protocol for WSN which is efficient in term of the energy usage of the whole network such that the network will not get disconnected because of the energy depletion of its nodes. Still there are so many routing algorithms in this field we are trying for a protocol in the real time network where the traffic is more and also congested by so many data sources sending their packets to the base station at the same time. We are proposing a protocol which selects the path with a high survivability factor at the same time it should try to select the one which has less interference from the other nodes as well as the environment [6]. For selecting the next hop node, our algorithm uses a criterion which is a function of the signal-to-interference-noise-ratio of the link between those two, the survivability factor the path from that node to the destination, and the path loss distance from that node to the destination.

II. Related Work

Routing protocols should be designed in such a way that it will be saving the energy as much as possible because energy sources are limited in sensor nodes. With the specialties of WSN, the lifetime of the network is a reflection of the lifespan of nodes. A node in the network dies, it may cause a situation that, the network suffers from some loss of connectivity. So, energy aware and lifetime prediction routing protocols are very important.

There are a lot of routing techniques in sensor networks that utilize the resources of the nodes of the sensor network with limited availability in a more efficient way. Those schemes will typically be trying for finding the minimum energy path for optimizing the use of energy at a node. In [4], the authors are taking a view that continually utilizing the lowest energy paths may not be optimal from the network lifetime perspective and for connectivity for a longer duration. This Energy Aware Routing Protocol proposed by R.C.Shah et al. has a basic idea which is for increasing the network survivability. In some cases, it may necessitate occasionally using the sub-optimal paths also, which may ensure that the optimum path is not getting energy depletion and hence the network will be gracefully degrading as a whole rather than get partitioned. In their approach, multiple paths between the source and the destination are discovered first. And then a probability of being chosen is assigned to each of those paths, which is done by an energy metric. When there is a packet to be sent, the source will choose one of the paths randomly from the list of paths already found out, depending on those probabilities. This ensures that any of the paths will not be used all the time, and that prevents energy depletion. This algorithm is a reactive routing technique and a destination-initiated query-driven protocol where the customer of the data is initiating the route request. A routing algorithm named Sub-Game Energy Aware Routing (SGEAR) is proposed to make better routing choices, in [5] by Dayang. S. et al. SGEAR take the residual energy of the nodes and the energy consumption of the path into consideration. Compared with Energy Aware Routing, SGEAR can provide stable routing choices for relaying nodes, and the energy of the network can still burn evenly. Moreover, this SGEAR algorithm is more suitable for being incorporated into sleep scheduling scheme and thus will prolong the network lifetime. That is, the major drawback of the protocol is that any path can be selected at any time. So sleep scheduling cannot be incorporated with this, which is a primary technique to increase the lifetime of a node. SGEAR is a better approach, in which a route is selected for the communication only for predetermined cycle time. After that cycle, another route will be used. So during a cycle, the nodes which are not in the selected path can get scheduled to sleep. Selection of the path for a cycle is done based on a metric called Path Survivability Factor.

A. Motivation

In our work we are trying to modify the protocol proposed by Dayang. S et al in [5] in such a way that, it suits for the real time communication in WSN. In the real time traffic there should be multiple sensors sending their sensed data to the base station. Sometimes more than one sensor node may transfer the data packet to the base station at the same time. Since the nodes in the sensor networks are using the wireless communication medium, and radio transceivers to send and receive packet, it is contingent to make interference. That means the routing protocol should consider the link quality and the possible interference and the noise level of the link before selecting a next hop node for communication. The existing algorithm keeps silence about these factors in its routing choice selection. So we are trying for a modification which will decide a routing choice at every hop by also considering the congestion in the link.

III. Proposed Protocol: Survivable Path Routing.

In our proposal, we are using a selection criteria for choosing the next hop node along the path that includes the information about the link between the current node and the next hop node. The best of such information is nothing but the signal-to-interference-and-noise-ratio (SINR) of that node. So the parameter for the selection of the routing choice is also a function of the SINR value of the link between the current node and the next hop node; which is a function of the path survivability factor alone in the existing protocol. The interference on the link has an influence in the power consumption also. That is if the interference on a link is high then the communication through that link causes more energy consumption. That is, in a multi hop WSN with multiple sources sending data at the same time, the power consumption may get decided by the SINR value of the link also; that means, stronger the signal interference then more the power consumption. Suppose communication is taken place on a link which has low interference, then the transmitter will send the signal with a particular power consumed; if the interference along that link increases it should have to increase the transmission power in order to maintain the same signal strength. That is to keep the communication quality same, more transmission power has to be used when the signal interference is stronger. Theoretically, Signal-to-Interference-Noise-Ratio (SINR) can be defined as follows. SINR measures the ratio of transmission signal strength to the sum of interference and the ambient noise [7]. In the case of a transmission edge e_i, the sum of interference and the noise at the receiver of that edge i.e, R_{e_i} can be expressed as in the Equation 1.

$$I_f\left(e_i\right) = \sum_{m:m\neq i}^{\cdot} G\left(T_{e_m}, R_{e_i}\right) p\left(T_{e_m}\right) + \eta_i \qquad (1)$$

Here $G\left(T_{e_m}, R_{e_i}\right)$ is the path gain between the transmitter T_{e_m} on the link e_m and the receiver R_{e_i} on the edge e_i. $p(T_{e_m})$ is transmission power of the transmitters T_{e_m} on edge e_m. And finally η_i is ambient noise around the receiver

node R_{e_i}.
Then the SINR value of an edge e_i can be defined as,

$$\theta\left(e_i\right)=\frac{G\left(T_{e_i},R_{e_i}\right)p\left(T_{e_i}\right)}{I_f\left(e_i\right)} \tag{2}$$

From the above equation it can be seen that when $I_f\left(e_i\right)$ increases, to maintain the same SINR value on the link, the power $p\left(T_{e_i}\right)$ needs to be increased accordingly. But, the increase of $p\left(T_{e_i}\right)$ may also enforce more interference on the other links. Therefore, those links also need to boost their transmission power to maintain the same signal strength and hence the communication quality. It may enlarge the whole power consumption of the network and may lead to less lifetime of the network. So from all of the previous points it is clear that, in the case of sensor network with multiple sources, the interference on the link and hence the SINR value is an important factor which is to considered more attention. So we are using this factor in the routing choice selection process of our proposed energy efficient routing protocol.

Furthermore, the routing choice selection is made on the basis of one more factor i.e., the path survivability factor of the multiple paths found out between the source and destination. The path Survivability factor of a path is the ratio of minimum power available value among the nodes of the path to the total energy consumption along that path. That is, if c is the total energy consumption of the path L, and a is the minimum power available value among the nodes in path L, then a/c can be defined as the path survivability factor.

A. The Routing Strategy

The proposed routing algorithm and its working are explained in this section. As stated earlier the algorithm designed is an attempt to have a protocol which will burn the energy of the sensor nodes gracefully and hence increase the lifetime of the network. It is considering the scenario in which there are multiple source nodes which send their sensed data to the base station simultaneously, and hence may having interference in the communication medium. The protocol is designed to work in such an environment, and to route the data packet through the path that have interference and noise as minimum as possible.

The proposed protocol is a reactive routing protocol. It is a destination initiated query driven algorithm. Destination node will initiate the process by sending the interest message. The protocol works in three phases.

- **Setup phase:** Destination node initiates by broadcasting the interest packet (Route Discovery packet) to all it neighbors which in turn rebroadcast it to all their neighbors and so on. At the end of this phase multiple paths from source to destination are found out, i.e., it will find all the topologically possible paths from the source to destination. This is the phase when the routing table is created.
- **Data Communication phase:** Source node will send the data to the next hop node which is selected from its routing table based on the defined path choosing factor. Every intermediate node will also select their relay nodes from their routing table based on this path choosing factor, as at the end of the setup phase the routing table is created at every node which contains the data about their own neighbors only.
- **Route Maintenance phase:** This phase will work in a specified interval of time. At the beginning of a cycle the sink will send a route maintenance packet, which will update the routing table entries of the nodes in the network, and hence keeps the information up to date.

At every node the next hop node is selected from its routing table based on the path choosing factor. The path choosing factor (PCF) is a function of three things that are survivability factor of the path through the next hop node, SINR value of the link between itself and the next hop node, and the distance from the next hop to the destination. That is,

$$PCF=\frac{SINR\times survivabilityfactor}{path\ loss\ distance} \tag{3}$$

The SINR value is the Signal-to-Interference-and-Noise-Ratio of the link between the current node and the next hop node. When the route discovery packet is received by a node it will calculate the signal strength of the received packet and calculate the SINR value for the link. And it will be stored in the routing table. Periodically it will be updated using the route maintenance packets. The survivability factor used is the logarithmic path survivability factor in order to overcome the drawback of simple path survivability factor in [3].

$$f\left(a,c\right)=\frac{\log a}{\log c} \tag{4}$$

Where a is the minimum power available value among all the nodes along the path and c is the total energy consumption of the path. The route discovery packet will contain these a and c values. The destination node will send the route discovery packet (interest packet) in which the value of a and c are, the remaining residual energy of the destination node and zero respectively. Since, the cost for communication from the destination to itself is zero; the value for c is set to zero. And there is only one node in the path form destination to itself; the minimum energy value should be its own residual energy. This interest packet will be send to all its neighbors. Upon receiving this packet, a node will check that, whether the received a value or its own residual energy is less. The lesser value is stored in the packet as a value which is to passed to its neighbors. The c value in that packet is set with the sum of the received c value and the cost for communication between the transmitter of the received packet and itself.

The path loss distance between the next hop node and the destination is also included in the path choosing factor. It is included to gain the advantages of the geographic routing technique. In geographic routing technique, it will select a node as the next hop which minimizes the distance to the destination. It has been proven that the path chosen by the geographic routing should be very near to the shortest distance path between the source and destination. So by including this distance also to the path choosing factor, the number of hops in the path selected can be minimized. Each of three phases is explained in detail below.

- **Setup Phase**
  - The sink node will initiate the process by sending the interest packet (route discovery packet) to all its neighbors. The packet contains a value which is set to the residual energy of the destination, and the c value which is equal to zero.
  - Upon receiving this interest message, each intermediate node i will add the received a value and the c value to the routing table in the corresponding entry.
  - Node i will calculate the SINR value of the received packet. This calculated SINR value also added to the routing table.
  - The packet will contain the coordinates of the sender of the packet and also the coordinates of the sink. So the coordinates of the sender of the packet will entered to the routing table entry corresponding to that node. And each node will memorize the coordinates of the sink.
  - The node will re-broadcast the interest packet to its neighbors. Before sending out it will do the following updates
    - Change the coordinates to its coordinates.
    - Compare its residual energy with the received a value, which is minimum, set it as a value of transmitting packet.
    - Add the received c value with the cost of communication between the sender and itself, and the resultant is stored as the c value of the transmitting packet.
  - Once it reaches the source, all the possible paths between the source and destination are get revealed.
- **Data Communication Phase**
  - Once the interest message reaches the source, it will start sending the sensed data packet to the destination.
  - For selecting the next hop node, it will use the routing table. In the routing table it is contained the SINR information, a value, c value, and the coordinates of each of its neighbors. It will calculate the path choosing factor of each node in the table. Which has the highest path choosing factor, it is selected as the next hop node.
  - While relaying each intermediate node will make the routing choice like the above. That is, it will select the node which has the highest value for the calculated path choosing factor among its neighbors.
- **Route Maintenance Phase**
  - To guarantee the effectiveness of each path the sink will periodically send the route maintenance packet to its neighbors. As they will resend it to their neighbors and so on.
  - While sending the route maintenance packet the current remaining energy is stored in as a value.
  - Upon receiving each node will recalculate the SINR value for the current packet, and the routing table is updated. All the fields in the routing table i.e., a value, c value, coordinates will be updated with the new information.

IV. Simulation Results

Simulation is carried out in OMNet++ simulator along with the Castalia framework. In each simulation the proposed protocol is compared with the existing Sub-Game Energy Aware Routing protocol. In all simulation the base station i.e., the sink node is placed at (0,0) and the other nodes are placed evenly in the simulation area. The simulation will last for 10,000 s. The simulation is carried out by changing the transmission power of the nodes in order to check the working of the proposed model in different interference levels. There are multiple source nodes placed randomly.

Fig 1 shows the average energy consumption. From the figure it can be seen that the proposed protocol consumes less energy as compared to the existing SGEAR protocol.

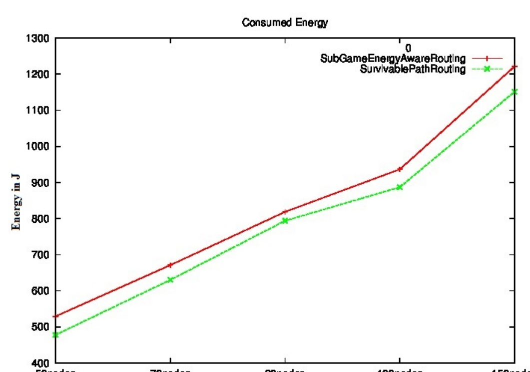

Figure 1. Average Energy consumption.

Figures 2, 3, 4 and 5 show the number of application packets received at the destination in both the protocols.

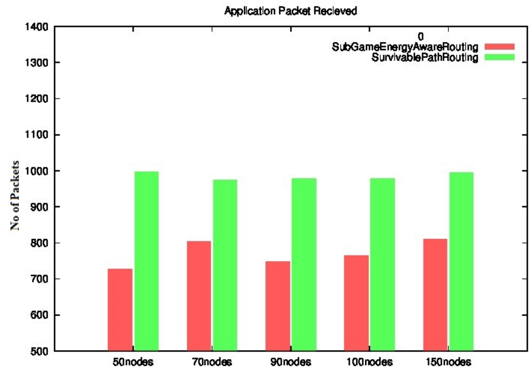

Figure 2. No of Application packets received. Transmission power is 50.69mW, and 5 source nodes in the network

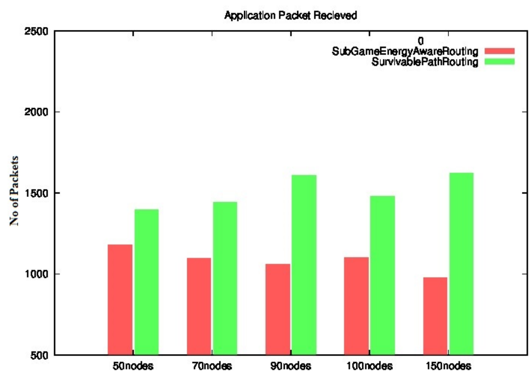

Figure 3. No of Application packets received. Transmission power is 50.69mW, and 10 source nodes in the network

Simulation is carried out with different transmission powers for the nodes in order to evaluate the change in interference and to check how the protocol will work in different scenarios.

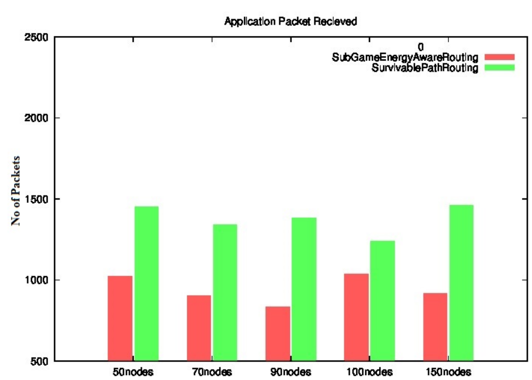

Figure 4. No of Application packets received. Transmission power is 42.24mW, and 5 source nodes in the network

From these figures, it can be concluded that the proposed protocol outperforms than the existing protocol. In all the cases the packet reception rate for the new protocol is higher than the existing protocol. This is because, there are multiple source nodes in the network, which will create interference on the other nodes. Since the existing protocol only consider the energy factor for the selection of the route, it may select the paths which are congested enough to drop the packet. And hence it is not able to reach the packet at the destination. So in the SGEAR protocol the number of received packets at the destination is less. On the other hand the proposed survivable path routing protocol will also consider the congestion in the communication medium for selecting the routing choice. It is more focused to select a path which has as less interference as possible. So the proposed algorithm can reach more packets at the destination. Number of packet drops is less in the new protocol

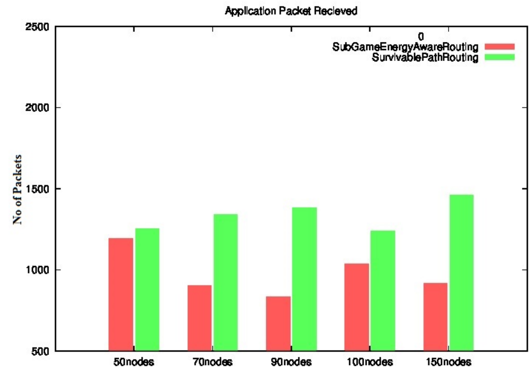

Figure 5. No of Application packets received. Transmission power is 42.24mW, and 10 source nodes in the network

Figure 6 shows the consumed energy of nodes in both the cases. It shows that the proposed protocol consumes less energy as compared to the existing one. This is happening because interference in the link will impose the node to use more power in order to maintain the signal quality. In the equation 2 for SINR, the power is in the numerator and the interference in the denominator. So if the interference increases in order to keep the signal strength the power has to be increased. So if the packet routed through the less interference path, the power consumption will also get reduced. So the proposed protocol has the less energy consumption.

Figure 7 shows the remaining energy at a particular node for a particular simulation. The graph is plotted for the remaining energy present at the node against the simulation time. From the figure it can be seen that the proposed protocol leaves more energy in the node than the existing one. That means the energy consumption at node level is also less in the case of new algorithm.

Figure 8 is showing the end-to-end delay for each packet received at the destination. From the figure it can be concluded that the proposed protocol works better to reach the packet at the destination early. That is, the end-to-end

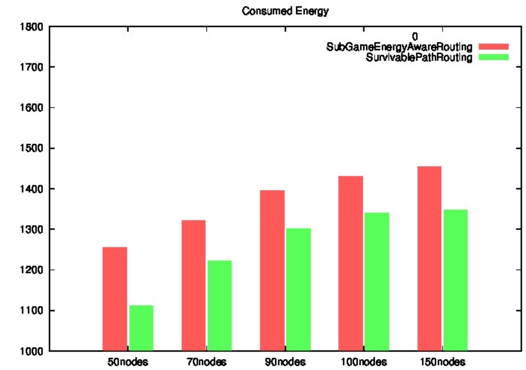

Figure 6. Average Consumed Energy

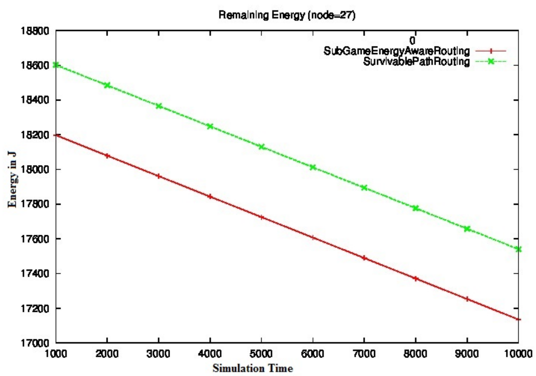

Figure 7. Remaining Energy of a particular node

delay of the packets is less for the proposed algorithm. It selects a path which has lesser number of hops towards the destination, hence it achieves decreased end-to-end delay for the packets. The new algorithm gains the advantage in Quality-of-Service measure also. So it will work well in delay constrained network.

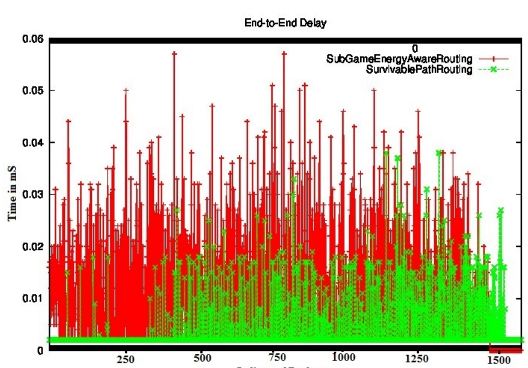

Figure 8. End-to-End Delay for the packets

V. Conclusion

The sensor nodes in WSNs have got only limited sources of energy and computing. The main constraint of these networks is the amount of energy consumption. The lifetime of a Wireless Sensor Network depends on its node's energy level. In most of sensor networks there is no way to recharge node's battery because of its unattended nature; therefore, efficient use of the available energy sources of the node is essential. Since the nodes in the sensor networks are using the wireless communication medium, and radio transceivers to send and receive packet, it is contingent to make interference. That means the routing protocol should consider the link quality and the possible interference and the noise level of the link before selecting a next hop node for communication. So the interference on the link and hence the SINR value is an important factor to be considered. So we are using this factor in the routing choice selection process of our proposed energy efficient routing protocol. This is an extension of the existing SGEAR algorithm. The new algorithm is designed to suit in the environment where the congestion is more and hence the interference on the link. The simulated results showing that the new protocol works well in the networks when the traffic is high, which imposes interference on the other links, than the existing algorithm. Our protocol has more packet reception rate, less end-to-end delay, as well as it consumes less energy.

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