Adjustable Range Routing Algorithm based on Position for Wireless Sensor Networks

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***Abstract*— In end to end message transmission, Single-Hop and Multi-Hop routing algorithms are the most common solutions available. Unfortunately, they are not optimal when implemented alone; therefore the answer is to find harmony between them. Nodes using Single-hop algorithms consume large amounts of energy as a result of sending the information through one hop distance, multi-hopping towards the destination might solve this problem but creates energy holes in the nodes widely used. The goal of this work is to balance the energy consumption among the sensor nodes, by implementing an adjustable transmission range routing algorithm based on sensor's position information and using long-hop communication. Our proposed algorithm, Adjustable Range of Transmission or "ART" which is a routing implementation developed that protects energy holes. It benefits from the aforementioned algorithms by finding a balanced point between them. ART utilizes Long-Hop Routing to send information to the Base Station "BS", over smaller number of longer hops. This is achieved by adjusting its transmission range power based on its position among nodes in the WSN.**

Keywords: Wireless Sensor Networks, Transmission Range, Node Degree, Network Lifetime.

I. INTRODUCTION

Certain applications in Wireless Sensor Networks, like Environmental and Disaster Monitoring, Surveillance etc., require large number of nodes [1] that are deployed in dense and hostile areas. It is almost impossible to manually replace batteries and configure each node in such a place. Consequently, nodes have to self-configure to build the topology that balances the network lifetime. One of the important drawbacks for the applications mentioned is that sensor nodes are resource-constrained, in terms of energy. When a great deal of power is spent, the network lifetime is affected and the sensor's batteries start to deplete, making the whole network inefficient. The main objective of WSN is to sense different types of environment and relay information to a Base Station "BS". So the energy spent on sensing and establishing a connection must be a priority. Energy is also consumed on computation but the largest depletion of resources is on reception and transmission, that is when the node transceiver is used.

Therefore in Wireless Sensor Networks an optimal scheme for exchanging information is the key for saving energy [2]. Single-hop or Multi-hop routing protocols might be used but either one have disadvantages in terms of energy. This work focuses mainly on Multi-hop with greedy forwarding decisions and the optimal "Next Hop" or "Forwarder" selected from a set of nodes. When a node using single hop communication transmits its package over a distance to its destination it consumes energy. In this case, distance and energy consumed, are proportional variables. The farther away a message is transmitted, the more energy will be consumed [8]. In this case single hop algorithms might not be very effective for conserving the network's lifetime. On the other hand Multi-hop algorithms solve single hop's disadvantage but also brings new issues to deal with. One of them is when a single node in a determined area depletes its energy, not only sensing will stop but also forwarding communication activity in this area. Therefore balanced energy consumption is crucial to achieve maximum performance in WSN. In Multi-hop communication, Energy holes sometimes form around Base Station "BS" making the whole network unbalanced.

Considering, energy consumption, hopping algorithms doesn't seem suitable for communication in WSN. In [2,3] a classification for Multi-hop communication in ad-hoc and sensor networks was created to demonstrate the drawbacks of Short-Hop or sometimes called Nearest-Neighbor Routing. In short Hop routing information is sent over many short hops and in Long-Hop Routing information is sent over smaller number of longer hops. It was proven that Long-hop methods are far more optimal. As discussed above, using multi-hop communication may cause energy holes surrounding the BS, because the relaying task cannot be well distributed among nodes. Better load distribution is obtained if a node can reach the BS in one hop. To obtain energy balanced consumption we apply Long-Hop technique to our proposed network algorithm "ART", controlling topology by varying transmission range for every node in the network. The main rule to define optimal routing is discussed in [1]. Specifying a transmission range that sometimes is adjustable can improve routing methods. Transmission range controls node Degree, which is the *"Neighborhood Size"* of a single node. Expanding node Degree reduces hop-count allowing the great benefits of Long-hop routing. The challenge in many algorithms is finding what transmission range is optimal. We propose the solution ART, which controls Network Topology varying transmission range in order to obtain load energy balancing and avoidance of energy holes. Simulations show that compared to Single-Hop and Shortest-Hop Algorithms, ART reduces accumulative energy consumption by close to 50% and 25% correspondingly.

The rest of the paper is structured as follows. In Section 2, topology controlled algorithms and energy aware methods are discussed as they relate to the work done in this paper. Section 3 Network and Energy Models are covered. In Section 4 ART's Outline is presented. Section 5, Route Setup Phase for our proposed solution "ART" is discussed. Section 6 includes Route Maintenance. Section 7 compares ART with two algorithms with WSN Simulation. And we conclude the work with Section 8.

II. RELATED WORK

We classify the most influential parameters or characteristics of a single node in WSN into the following categories:

1. Location
2. Remaining energy
3. Transmission & Reception power
4. Node degree.

These parameters vary and are different for every node in the network, using such parameters we can compare nodes in a determined neighborhood and select the best one to forward data packets. Weighted-Routing Algorithms use a selection of these parameters to run, and are effective in terms of energy but not in reliability. Some other techniques focus on one parameter to improve another one. In our proposed algorithm, location and transmission power parameters are used together as a weighted algorithm to improve network lifetime. Therefore, in ART, decisions are based on the location of nodes, location of the destination and position of the neighboring node that forwarded to message. Most of localized algorithms match greedy algorithms according to [12] where simple local behavior attains a desired global objective. In shortest-

In Topology-controlled algorithms the objective is to adjust the transmission power to reduce energy consumption, an example for this case is [4] TRAT that is a Traffic-Aware Topology Control Algorithm for Energy Efficiency in WSN that controls the number of active nodes and adjusts transmission power with traffic information. In Energy-Aware Algorithms, remaining energy is considered in order to select an optimal routing path, a related work for this case is [5] HEAR "Hop-based Energy Aware Routing Algorithm for WSN" which considers that hop number is valuable influence on energy consumption and provides a threshold to either use Single-Hop or Multi-Hop based on the node's position. In [11] various centralized and distributed algorithms were developed in which the objective is to conserve energy by exploiting redundancy in the network and where each sensor can adjust its sensing and transmission power.

III. NETWORK AND ENERGY MODEL

In this section we describe the network and the energy model used, as well as some basic assumptions. Similar to [6] we assume that the network might be composed by thousands of nodes deployed non-uniformly. Nodes are dispersed in a two-dimensional space [X, Y], with Base Station "BS" at a fixed position and with unlimited resources of energy. We assume that nodes are location-aware and their energy consumption is non-uniform. In this network we consider the transmission range of a node to be adjustable according to its location.

Protocols discussed before use different communication methods, two of the most important are single-hop and multi-hop. As mentioned above most of the energy consumed is while transmitting data but we also consider energy spent on reception. Assuming node A, wants to communicate with *BS* over distance *d*, from source to destination there is *n* nodes and the distance between the nodes is *r* as shown in Fig 1.

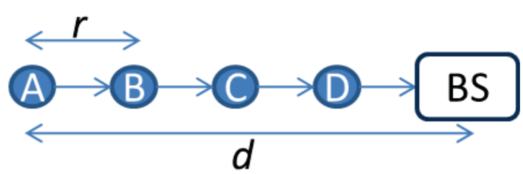

Figure 1. First Order Radio Model

We use the energy consumption radio model [7, 8] "First Order Radio Model". Considering we want to transmit a single k-bit message from node "A" located at a distance d from the BS using single-hop communication the radio will spend E_{Tx} to transmit a message k-bit over a distance d:

$$E_{Tx}(k,d) = k * E_{elec} + k * \epsilon_{amp} * d^2,\ if\ d<d_0 \qquad (1)$$
$$E_{Tx}(k,d) = k * E_{elec} + k * \epsilon_{amp} * d^4,\ if\ d\geq d_0 \qquad (2)$$

Considering that the radio consumes, $E_{elec}=50\ nJ/bit$ to run transmitter or receiver, $\epsilon_{amp}=100\ pJ/bit/m^4$ for the transmitter amplifier and $\epsilon_{fs}=10\ pJ/bit/m^2$ for free space model of transmitter amplifier. Assuming a r^n path loss due to channel transmission, *"n"* values can vary from 2 to 4, considering a distance threshold of:

$$d_0 = \sqrt{\frac{\epsilon fs}{\epsilon_{amp}}}\,(m)$$

In free space as (1) a 2 path loss exponent is used for propagation, and in (2) a value of 4 is used for relatively lossy environments.

When a single k-bits message, needs to be received the radio spends E_{Rx}:

$$E_{Rx}(k) = k * E_{elec} \qquad (3)$$

When using multi-hop routing, instead of just one high energy transmission, each data message must go through n transmits and n receives, to forward the data the radio of a single node spends E_{Fx}:

$$E_{Fx}(k,d) = E_{Tx}(k,d) + E_{Rx}(k)$$
$$E_{Fx}(k,d) = 2k * E_{elec} + k * \epsilon_{fs} * d^2,\ if\ d<d_0 \qquad (4)$$
$$E_{Fx}(k,d) = 2k * E_{elec} + k * \epsilon_{amp} * d^4,\ if\ d\geq d_0$$

Depending on the electronic device sometimes the energy spent on multi-hop is larger than single hop. The characteristic distances [13] vary according to hardware energy consumption and path loss coefficient *"n"*. Path loss of radio transmission grows with distance in a multi-hop routing behavior. A characteristic distance *"d_c"* (5) usually adapts the appropriate number of hops to reach a destination. From (4) we concluded that a node uses *"E_{FX}"* energy to forward a message from one node to another.

$$d_c = n\sqrt{\frac{Efx(k,d)}{\epsilon fs(n-1)}}\,(m) \qquad (5)$$

IV. ART OUTLINE

Sensor nodes build routes using two different techniques: 1) Proactive and 2) Reactive. In Proactive techniques [9, 10] the information is shared in a timely manner. The routing infrastructure is created and maintained periodically, not concerning network behavior. Proactive approach improves routing by constantly renewing routes but degrades network lifetime, because of constant resource consumption. In Reactive techniques the information is shared in an event manner. The nodes will deliver the data to the "BS" only if some predefined threshold is reached and routing infrastructure will be created only when a node needs to transmit data. Some of the applications discussed before work with reactive techniques (e.g., disaster monitoring, fire intrusion detection, and surveillance), because the network is usually saving energy in idle mode. When an event occurs, the network topology changes, traffic loads increase and large amounts of energy are consumed.

In ART, nodes build routes reactively, by varying transmission range, according to their position so when an event or link failure occurs; ART uses this position information to find correct new routes on-demand.

As mentioned in Section 2. Node Degree is a particular parameter that a single node possesses, and is strongly bounded to transmission range. As stated in [1], the results of a particular transmission range rely upon the physical dimensions and node density of the WSN. Is important to mention once again, that transmission range controls Node Degree or sometimes called *"Neighborhood Size"*, incrementing node Degree balances network lifetime, by reducing hop-count.

Let N be a set of nodes in 2D Euclidian Space R^2. To every pair of coordinate points (x, y) a real number is assigned as *Dist*, where $Dist_{ij}$, represents the distance between two nodes, *"i"* and *"j"*, such distance requires certain axioms to be satisfied:

1. $Dist_{ij} == Dist_{ji}$
2. $Dist_{ij} > 0$
3. $Dist_{ij} + Dist_{jk} \geq Dist_{ik}$

A node "*j*" can be defined as a neighbor of "*i*" if $Dist_{ij}$ satisfies the axioms above and if:

$$Dist_{ij} \leq R_i$$

Therefore, the relationship of all the neighboring nodes of *"i"* can be called Degree of "*i*" or D_i where:

$$\forall n \epsilon D_i\!: Dist_{in} \leq R_i$$

To select the set of nodes "*S*" that forward a broadcast packet sent from source node "*i*", towards the BS, Distance to BS "*DistBS*" is used where the Set

"S" includes nodes that fulfill the following requirements:

1. $\forall n \epsilon S_i$: $Dist_{in} \leq R_i$
2. $DistBS(i) > DistBS(j)$

As shown in Fig. 2 source node "i" has a determined R_i where every node inside circle denoted by R_i is a neighbor of "i". Neighbors in lined area delimited by comparing distance towards the "BS" are all part of "S_i", the set of nodes that forward a broadcast packet.

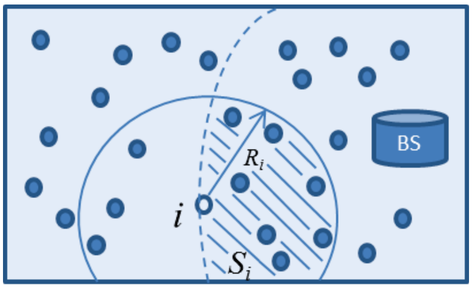

Figure 2. Forward node set "S". Where "i", is the source node, R_i is the transmission radius of "i" and S_i is the Forward node set

Let's assume that in a random deployed sensor network, every node holds at least one neighbor and information is always sent in direction towards the "BS". For "i" with S_i delimited by R_i there has to be a neighbor, "n" that is the closest to "i" based on its distance, compared to other nodes in, $S_i = \{n \mid n \epsilon S_i : Dist_{in} \leq R_i \;\&\; DistBS(i) > DistBS(n)\}$. Therefore the Nearest-neighbor (n) of node "i" based on distance is:

1. $\forall(n) \epsilon S_i$: $(R_i - Dist_{i(n)}) = K_{(n)}$
2. $Dist_{Max}(K_{(n)})$ = (n| *the node "n" closest to node "i"*)

Where $K_{(n)}$ corresponds to a value for every node that has a neighbor, representing the difference of a node's range when transmitting a message to a neighbor which is at distance $Dist_{i(n)}$ away, as shown in Fig. 3.

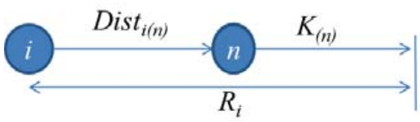

Figure 3. Nearest or farthest neighbor using constant K

Basically, $Dist_{Max}(K_{(n)})$ represents the node "n" with largest distance of $K_{(n)}$ in S_i. In case of a nearest-neighbor transmission algorithm, the node in S_i with largest distance of $K_{(n)}$ will be selected as next hop. In case of selecting the node that is farthest away from the sender inside its Forward node set or "S" a different approach is considered as:

$Dist_{Min}(K_{(n)})$ = (n| *the node "n" farthest to node "i"*)

Now $Dist_{Min}(K_{(n)})$ represents the node "n" with the shortest distance of $K_{(n)}$ in S_i. In case of a greedy transmission algorithm as used in this work, the node that is closer to "BS" and inside "S" will be selected as next hop or forwarded.

In ART, the forward node set "S" is built and maintained through a reactive process. A deterministic approach is used in which the forward node set can be selected based on location information. In different location-based algorithms nodes have non-forward state by default, and this might be changed to forward state, based on different criteria, like position or remaining energy.

V. ROUTE SETUP PHASE

When setting up a route, a common strategy is the fact that at each hop, the advancement shall be made towards the Base Station "BS", so the forward state of each node in the whole WSN is depending on its distance to the BS.

Step 1: When nodes in the WSN are first distributed, the BS gets the location information of every node via GPS, Received Signal Strength "RSS", Time in Flight or any related localization method.

Step 2: Define a Distance Threshold value "T", for every sensor in the network with the purpose to vary R as:

If $DistBS(i) < T$, then a larger transmission range is set "R_1".
Else if $DistBS(i) > T$ a smaller transmission range is set "R_2".

Density, Network Size and Number of nodes are important criteria for setting up a threshold like "T", when varying node degree according to position. Radio coverage in a high dense network might use less energy than a low dense network when using the same type radio device. Density in the network depends strictly on:

1. Network size
2. Number of nodes
3. Topology of Deployment

Step 3: The nodes are separated into two groups according to T:

1. "G_1", which is closer to the BS, nodes transmit using a larger Range R_1 than predefined "R", ($R < R_1$).
2. "G_2", which is farther away from the BS, nodes transmit using a smaller Range R_2, than "R", ($R > R_2$).

Different predefined Range "R" may be set depending on density and size of the network deployment. For Example, nodes in G_1, $R_1=2(R)$ or for nodes in G_2, $R_2 = R/2$. Fig. 4 shows Step 2 with nodes closer to BS using a larger degree than those far away from BS.

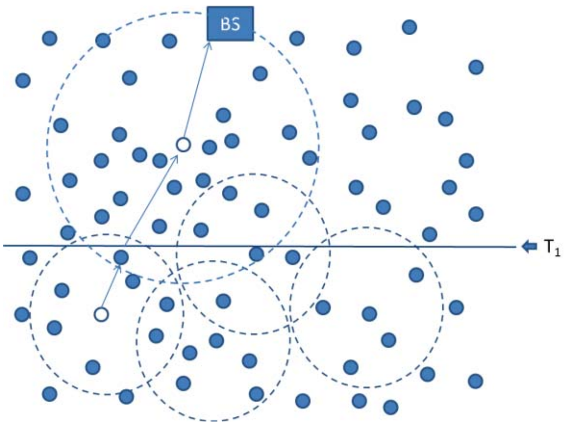

Figure 4. Nodes adjust their transmission radius based on their position.

As nodes farther away from the base station will use smaller transmission range, their degree will be smaller, and they will have fewer neighbors. Nodes closer to the base station will use a larger transmission range, thus having more neighbors than those farther away. Large degree provides a transmitter the opportunity to choose among a larger selection of nodes, some of them with different quantities of energy, others closer to the BS, or farther away from it. A great benefit of using ART is that it protects the energy hole around the BS. Most of the nodes in "G_1" that are closer to the BS, are able to reach the BS in a single hop using a larger "R_1". Nodes farther away from the BS "G_2" will be forced to use multi-hopping to reach the Base station, because they use shorter Range R_1, until the packet is transmitted to "G_1"a node closer to the BS, which holds a larger node degree, possibly including the BS itself.

As shown in Figure 5, we consider Fixed and Varied Parameters. Distance to BS, is a fixed parameter and cannot be changed, unless a node dies or a link fails. According to our work Transmission Range is a varied parameter.

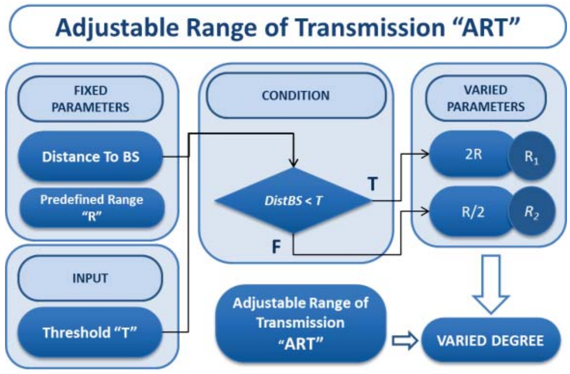

Figure 5. Adjustable Range of Transmission "ART"- Flow Chart

VI. ROUTE MAINTAINANCE PHASE

Maintenance in ART is done reactively as discussed in Section 4. Transmitting node *"i"* has a waiting time, if the waiting time finishes and *"i"* hasn't received the response message from *"j"*, then is considered that *"j"* is already dead and *"i"* removes it from its routing table. After detecting the link failure, the transmitter node will restart the route setup and choose another node to retransmit the data. If re-transmitter node *"k"* is unable to find an appropriate node to forward data from source, then an error message will be sent back to transmitting node *"i"* and the route will be deleted and a new route will be created.

VII. SIMULATION RESULTS

Experiments were run using MATLAB and a 100X100 coordinate plane. The simulation of ART was done with 100 random nodes network as shown in Figure 5. Each sensor sending a 2kbit data packet to the BS during each round of the simulation and two transmission range of 70 and 30 were used.

1. R_1=70 (Used for nodes closer to BS; "G_1")
2. R_2=30 (Used for nodes far from BS; "G_2")

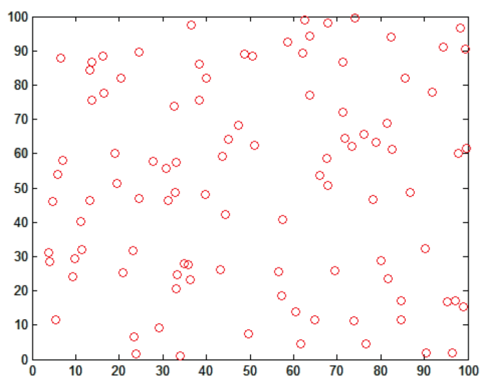

Figure 6. 100-Node random network, with a 100X100 Cartesian plane.

As stated before, the direction of packets being forwarded is always towards the Base Station.

As shown in Fig. 6, Single-Hop and Multi-Hop with greedy forwarding were used to compare ART's performance. The average energy consumption of 100 nodes is shown, with two different "Transmission Range" and the overall energy consumption after 100 rounds. Multi-Hop shows poor performance because of unbalanced distribution of individual distances. Single-Hop shows a better performance comparing to Multi-Hop. It is clear from Fig. 7, that the performance of ART has lower accumulative energy consumption comparing to the former two algorithms.

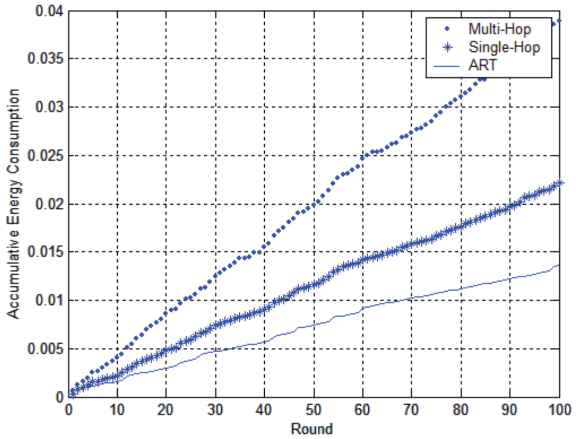

Figure 7. Accumulative Energy Consumption per Round

VIII. CONCLUSIONS AND FUTURE WORK

It is possible to find a proportional middle point between Single-Hop and Multi-Hop Algorithm by using the advantages of both at the same time. ART uses Long-Hop routing to prove this, by adjusting transmission radius, as shown in the simulation ART out-performs other existing algorithms. Relying nodes should be competent and have, good position with respect to the BS, large Degree and reasonable energy resources. Further improvement is desired for applications that may use sparse node networks and my cause voids in retransmission, thus future work is to use position-based routing or geographical routing, to vary range radius in sparse networks and avoid communication failure.

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