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Energy Efficient Protocol for Clustered Cooperative Sensor Network

Ms. Pallavi H. Chitte, Mr. D.K. Chitre

Abstract— **Energy efficiency is the major problem in wireless sensor networks. We introduced the Cooperative communication protocol in wireless sensor networks (WSN) for establishment of cooperative clusters during transmission of data in a cooperative way. In the cooperation process of this cooperative transmission protocol, recruitment policy helps the nodes to co-operate each other. Cluster head on the one node thick path recruit neighboring nodes to assist in communication.**

To verify effectiveness of our cooperative transmission protocol various factors such as capacity, end-to-end robustness of the protocol to data-packet loss, along with the trade-off between energy consumption and error rate for cooperative network protocol are analysed. The packet failure probability and bit error minimization is derived for analysing end-to-end robustness of the protocol to data-packet loss and for analysing capacity, throughput rate is considered. Energy consumption analysis is done with the help of transmission power and number of selected nodes for cooperation. Cooperative transmission protocol comparison with other cooperative and non-cooperative schemes is done for performance analysis. The implementation results are elaborated through graphs. We have shown the performance of Cooperative transmission protocol through end-to-end robustness of the protocol to data-packet loss, capacity and energy consumption. Considering all these parameters it can be shown that longer lifetime of network can be achieved for cooperative transmission protocol.

Index Terms— **Wireless Cooperative Network, Wireless Sensor Network (WSN), Cooperative transmission, transmission cluster, receiving cluster.**

I. Introduction

In a cooperative wireless network, all nodes can transmit information cooperatively. Each node can be a source node that transmits its information or it can be a relay node that helps to forward information of other nodes. Sometimes the cooperation strategy is based on the decode-and-forward (DF) protocol which comprises two transmission phases. In first phase, the source node sends the information to its next node on the route. In second phase, the relay node decodes the information it receives from the source and helps forward the correctly decoded information. In cooperative networking, individual network nodes can cooperate to achieve network goals in a coordinated way, and the cooperation can take place in a cross-layer fashion. Successful cooperative networking can prompt the cost-effective development of advanced wireless networks. Cooperative communication with single relay selection is a simple but effective communication scheme for energy constrained networks [2]. Node within a cooperative communication group with highest residual energy becomes the cooperative-group-head and it is responsible for data aggregation and the communication within the cooperative group. The group head pays role of BS for neighbouring clusters. Cooperative techniques utilize the broadcast nature of wireless signals by observing that a source signal intended for a particular destination can be "overheard" at neighboring nodes. These nodes are called *relays*, *partners* or *helpers*. Such relays process the signals they overhear and transmit it towards the destination. The relay operations can consist of repetition of the overheard signal (obtained, for example, by decoding and then re-encoding the information or by simply amplifying the received signal and then forwarding) or can involve more sophisticated strategies such as forwarding only part of the information, compressing the overheard signal, and then forwarding it [6].

In this paper our Cooperative transmission protocol showing the results of how the transmission ranges in the network affects the energy of our protocol as compared to other schemes and how failure probability of node in the network vary with transmission power variation. Our protocol increases the transmission reliability in comparison to the other presented schemes. Also we suggested one criterion for selection of appropriate cooperative nodes and the cluster head.

II. The Cooperative Transmission Protocol

In this cooperative communication model, every node on the path from the source node to the destination node becomes a *cluster head*, which performs the task of recruiting other nodes in its neighborhood and coordinates their transmissions. We called route from a source node to a sink node as "*having a width*" path which is a multihop cooperative path. Figure 1 shows, a *sending cluster*, a *receiving cluster* and cooperation of each cluster in transmission of packets.

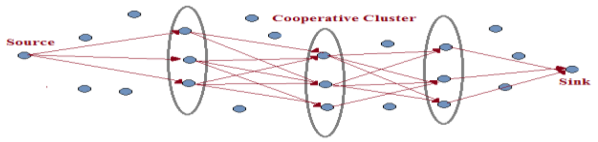

Figure 1 Cooperative transmission Scenario

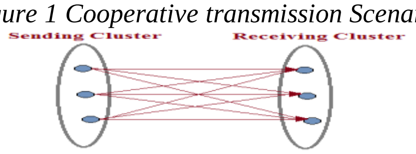

Figure 2 Cooperative transmission and reception scenario

In Figure 2, the model for Cooperative transmission and reception for a single hop is depicted where every node in the receiving cluster receives from every node in the sending cluster. Sending nodes are synchronized, and the power level of the received signal at a receiving node is the sum of all the signal powers coming from all the sender nodes and the mechanism for error detection is incorporated into the packet format, so a node that does not receive a packet correctly will not transmit on the next hop in the path. And thus it reduces the likelihood of a packet being received in error. Here we discuss two important phases our cooperative transmission protocol: *routing phase* and "*recruiting-and-transmitting*" phase.

A. Routing Phase

This phase find a "*one-node-thick*" route from the source node to the sink node which undergoes a thickening process in the "*recruiting-and-transmitting*" phase. Information about the energy required for transmission to neighboring nodes is computed. This information later used for cluster establishment in the "*recruiting-and-transmitting*" phase for selecting nodes with lowest energy cost.

B. Recruiting and retransmitting phase

In this phase, the nodes on the initial path become cluster heads, which recruit additional adjacent nodes from their neighborhood. The inter-clusters distance(s) (β) is significantly larger than the distance between nodes in the same cluster because the cluster heads recruit nodes from their immediate neighborhood. *Recruiting* is done dynamically and per packet as the packet traverses the path. The cluster head initiates the recruiting by the next node on the "one-node-thick" path. Once this recruiting is completed and the receiving cluster is established, the packet is *transmitted* from the sending cluster to the newly established receiving cluster. *Recruiting* and *transmitting* is done dynamically per hop, starting from the source node and progressing, hop by hop, as the packet moves along the path to the sink node. The receiving cluster of the previous hop along the path becomes the sending cluster, when data packet is received by it and the new receiving cluster will start forming. The next node on the "*one-node-thick*" path becomes the cluster head of the receiving cluster. The receiving cluster is formed by the cluster head recruiting neighbor nodes through exchange of short control packets such as RR, REC, GR, CL, CF. Then, the sending cluster head synchronizes its nodes, at which time the nodes transmit the data packet to the nodes of the receiving cluster. Medium access control is done in the *"recruiting-and-transmitting"* phase through exchanges of short control packets between the nodes on the "*one-node-thick*" path and their neighbor nodes [1]. Operation of the "*recruiting-and-transmitting"* phase is demonstrated in the Figure 3(a) to Figure 3(f).

Another criterion of selection of Cluster Head can be done based on the appropriate position and energy computing of node where Source broadcasts control packets and nodes within the communication range of source node and located at appropriate position correspond to source node. These nodes will contend for cluster head according to their own energy. The one with highest energy capacity gains the complete scenario and will act as the direct agent of source node. Then

The head broadcasts control packets to decide on cluster head of next hop. Repeating above process till a complete route containing cluster head is established and then cluster head performs the clustering. It implements the recruitment of cluster members according to the position and energy of neighboring nodes [4].

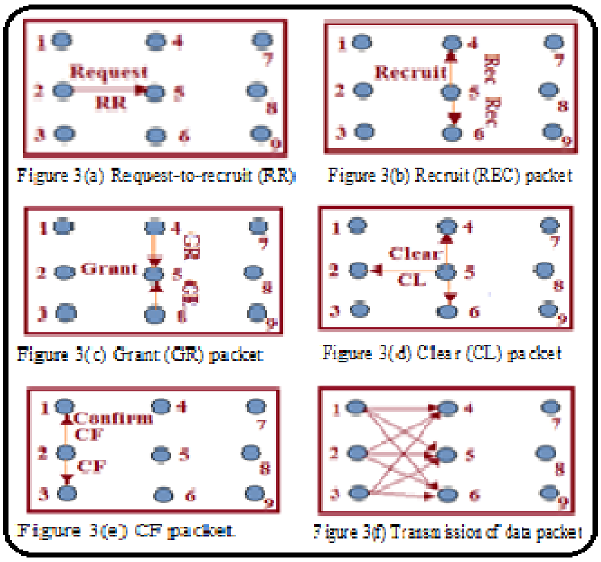

Figure 3(a) Request-to-recruit (RR)
Figure 3(b) Recruit (REC) packet
Figure 3(c) Grant (GR) packet
Figure 3(d) Clear (CL) packet
Figure 3(e) CF packet
Figure 3(f) Transmission of data packet

D. Control packets

The control packets that are used in the two phases of Cooperative transmission protocol are given below:

a. Request-to-recruit (RR packet)

The format of RR packet includes: the *id of the sender node* (node 2 in our example), the *id of the receiver node* (node 5 in), *the sink node id*, and the *NAV* field that contains the estimated transmission time of the data packet. The *NAV* field serves to indicate when the channel will become available again for other transmissions.

b. REC packet

The REC packet contains the *sender node id*, the *receiver node id*, the *id of the next node* on the path (node 8 in our example), and the *maximum time-to-respond*.

c. GR packet

The GR packet sent from node contains the *id of the originator of the REC packet* and the *sum of the link costs of the receiving link and the sending link*. A node can be involved in a single recruiting process at any time, i.e., a node can have only one outstanding GR packet. A node chosen to cooperate cannot be involved in another recruiting process until the transmission of the current data packet is fully completed, i.e., received and sent to the next cluster by the cooperating node.

d. CL packet

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A CL packet contains the *id of the cooperating nodes* and an *updated value of NAV*. Nodes that see their ids in the CL packet form the receiving cluster for this hop and the sending cluster for next hop. Other neighbor nodes that sent GR packets but do not see their ids in the CL packet will not participate in the cluster. To avoid interference: (1) if any node that receives an REC packet, whether it is cooperating or not, it has to wait for the transmission of the data packet to be fully completed before it can get involved in another recruiting process, also (2) if any node that overhears any of the control packets sent by any other node will not get involved in any recruiting or any transmission operation until the transmission of the data packet is fully completed. If a data packet was not received at the receiving cluster head node, or was received in error, the packet is considered to be lost and the whole *"recruit-and-transmit"* phase will restart again. A timer is associated with every exchange of control packets so that if a crucial control packet is lost, the *"recruit-and-transmit"* phase will restart again.

e. CF packet

The CF packet contains *the waiting-time-to-send* and *the transmission power level*. The transmission power level is the total transmission power (a protocol-selectable parameter) divided by the number of the nodes in the sending cluster.

II. Related Work

For performance evaluation of Cooperative transmission protocol, its performance comparison is done with the other three schemes such as Cooperation Along Non-cooperative path (CAN) protocol and the other two non-cooperative schemes that are "*disjoint-paths*" scheme and "*one-path*" scheme.

1. CAN Protocol

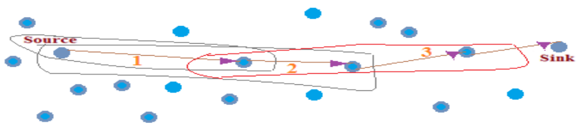

Figure 4(a) CAN protocol.

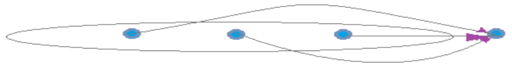

Figure 4(b) CAN reception model.

In CAN protocol, sender node transmit data packets to all the nodes along the path instead of sending once per hop. Here a"*non-cooperative path*" between the source and the sink nodes is found first and then the last *m* predecessor nodes along the non-cooperative path cooperate to transmit to the next node on the path.

2. Disjoint-paths scheme

In the disjoint-paths scheme, nodes form a number of disjoint paths from source to sink. The same information is routed individually along the different paths with no coordination between the nodes on the different paths.

3. One -path scheme

In the one-path scheme, first the one-node-thick path is discovered and established. Then, each node on the path transmits with power equal to the sum of transmission powers of all the cooperating nodes in a cluster. The analytical and simulation results of our cooperative transmission protocol are compared throughout the paper to the results of the CAN protocol, the disjoint-path and One -path schemes.

III. Methodology

A. Cooperative Transmission Protocol

Let the nodes in the cluster be indexed from 0 to m-1. We denote the transmission pattern of nodes in a sending cluster by a binary representation $b_{m-1}.........b_1b_0$ according to which node transmits if $b_j=1$ and does not transmit if $b_j=0$. A node does not transmit when it receives a packet in error from the previous hop. We denote the reception pattern of nodes in a receiving cluster by a binary representation $b_{m-1}.........b_1b_0$ according to which node j correctly receives the packet if $b_j=1$ and receives the packet in error if $b_j=0$. For example, for m=4, the binary representation of 1010 of the sending cluster and the binary representation of 0101 of the receiving cluster means that nodes 1 and 3 in the sending cluster transmit the packet, while in the receiving cluster nodes 0 and 2 correctly receive the packet and nodes 1 and 3 incorrectly receive the packet. Let g_I^J be the probability that node with binary representation $I= u_{m-1}.........u_1u_0$ transmit a packet of length L bits to nodes with binary representation $J= b_{m-1}.........b_1b_0$ across a single hop, and let SNR_j be the SNR of the received signal at node j, then

$$BER = f\left(SNR_j, \sum_{i=0}^{m-1} u_i\right)$$

$$g_I^J = \prod [(1-b_j)(1-(1-BER)^L) + b_j(1-BER)^L]$$

B. Calculation of failure probability

i. Cooperative transmission protocol

Let vector v(i) be the binary representation of integer *i*. We define: $g_{v(0)}^{v(0)}=1$; $g_{v(0)}^{J}=0, J\neq v(0)$. *Let* A_{JK} be the probability that a packet reaches the k^{th} hop to nodes with binary representation *J*, given that at least one copy reaches *k-1* hop, then

Where, $$A_{JK} = \sum_{I=1}^{2^m-1} g_{v(I)}^{J} A_{v(I)k-1} \quad (1)$$

$$A_{J0} = \begin{cases} 1, & for \quad J=v(2^{[m/2]}) \\ 0, & otherwise \end{cases}$$

Now, let B_{CwR}^h be the probability of failure of a packet to reach any node by the k^{th} hop.

$$B_{CwR}^h = \sum_{k=1}^{h} A_{v(0)k} \quad (2)$$

In this way failure probability, that the packet does not reach the sink due to reception error(s) along the path, is calculated.

ii. CAN protocol

Let Xi=0 represent the event that a packet is not received at the h^{th} hop along the non-cooperative path, while Xi=0 is the complementary event. Let $B^h{}_{CAN}$ be the probability of failure of a packet of length L bits to reach the node at the h^{th} hop

$$B^h_{CAN} = P_r(X_h = 0) = \sum_{I=1}^{m} P_r(X_h = 0 X_{h-1} = u_0 .... X_{h-1} = u_{n-1}) P_r(X_{h-1} = u_0 .... X_{h-n} = u_{n-1})$$

Where n=min (m, h). The first term in (7), the probability that a packet is not received at the h^{th} hop given that the last n nodes transmit with binary representation I=un-1 …u1, u0.

iii. One–path scheme

The analysis in this case is similar to the disjoint-paths case, but with one path only and each node transmitting with power of, where $\sum_{j-1}^{m} P_t(j)$ is the transmission power of the jth node. Let P_t (j) is the probability of failure of a packet to reach the h^{th} node of the one-path scheme, then

$$B^h_{noC} = 1 - [1 - (f([(m.P_t)/(P_n d_\gamma \beta^\gamma)],1))^{Lh}]$$

C. Calculation of the Cost of Links

As mentioned in the *Recruiting and retransmitting* phase potential cluster member should compute the link costs. This cost is the sum of receiving link and sending link of a node. Receiving link from cluster head of front hop (or source) and node itself, and sending link concerns cluster head of next hop (or destination) and node itself. The link cost between node *i* to node *j* : $C_{i,j}$ calculated by node *i* as:

$$C_{i,j} = \frac{(e_{i,j})^\sigma}{R_i / R_{avg}} \quad (3a)$$

Where, $e_{i,j}$ is energy cost of the link, R_{is} residual battery energy of node *I*; R_{AVG} is average residual battery energy of the neighbors of node. Energy cost of a link is the transmission power required for reception at a particular bit error rate. Nodes determine the energy costs of links by listening (or overhearing) transmissions during the routing phase. The protocol-selectable parameter controls the weight of each factor in the total cost. From equation (3) of link cost, nodes with small residual battery capacity are less likely to be recruited in this phase [1].

Another method to calculate the link cost to achieve energy efficiency is:

$$C_{i,j} = \frac{(e_{i,j})}{R_i / Rneighbor} \quad (3b)$$

Where $e_{i,j}$ is the energy cost of the link that required for reception at a certain bit error rate. Node can obtain it through overhearing during the routing period. R_i is the remaining energy of node *i*. $R_{neighbor}$ is the average remaining energy of the neighbors of node i. Cluster head selects among potential cluster members. Those with large remaining energy capacity are more likely to be recruited [4].

D. Error calculation in Cooperative transmission

Here, the Cooperative transmission model is similar to MISO case and protocol selectable parameter m is the number of cooperating nodes in the network. Considering, a known SNR at the receiver, the probability of an error at the receiver is given by

$$P(error) = f(SNR, m) = (1 + (SNR/2))^{-m} \quad (4)$$

We assumed that the power attenuation due to distance is carried out by $d\text{-}\gamma_{i,j}$. Where, $d_{i,j}$: the distance between node to node, γ is the attenuation exponent. In particular, let P_n be the noise power at the receiver and P_t is the transmitter transmission power measured at nominal distance equal to 1. When a packet is transmitted from node to node, the SNR measured at the receiver j is computed as,

$$SNR = [(P_t/d_{i,j})/P_n] \quad (5)$$

In other words, to achieve a certain value of SNR, the transmitter needs to transmit with the power of,

$$P_t = [SNR. \; D\gamma_{i,j} \; *P_n] \quad (6)$$

The bit error probability is then terminated by (4). We also assume that for a packet to be successfully received, all the bits in the packet must be successfully received.

E. Energy consumption

We compare the energy consumption of our cooperative transmission protocol to the CAN protocol and the one-path scheme. For making meaningful comparison of energy consumption of any two schemes, we kept failure probability equal for the compared schemes. In our Cooperative protocol, one-hop energy consumption of the transmissions of the control and data packets between two cooperative clusters of nodes, with m cooperating nodes in each, is analyzed. For energy consumption of this cooperative scheme, we assume some failure probability as P_f and the probability of bit error is a function of the *SNR* of the received signal. For every value of the failure probability P_f, we calculate the needed transmission power of a single node P_t from (2) to (5). We assume that the power consumption for the cooperative protocol is $m^2 \cdot P_t$ as we need m transmissions per hop, with each transmission being of the type *m-to-1*. For CAN protocol, we assume, the power consumption is $m.P_t$ and for the one-path scheme we assume, the power consumption is P_t.

IV. Results and Analysis

A. Simulation Results

We use simulation to evaluate the performance of our protocol. Network simulator ns2 is used for simulating the results and multi-hop scenario. Considering the x-dimension of topography as 500 and y-dimension of topography as 500, simulation time of 200 sec, total number of nodes in the network=100 and initial energy = 100J. Nodes are placed randomly and the numbers of cooperative nodes m is 7.The source and sink node are picked randomly. The metrics that we use for evaluation are: transmission power and energy consumption. Our protocol curves are shown as "*CwR*", the CAN protocol curves are shown by "CAN", disjoint paths schemes curves are shown as "*noc*" and One-path schemes curves as "*One*". These curves are plotted in graph with different colours. We analyse different values of packet failure probability (P_f) for different values of transmission power. Figure 5 depicts Failure probability vs.

transmission power.Considering different power levels; our cooperative transmission protocol has lowest failure probability than the compared schemes.

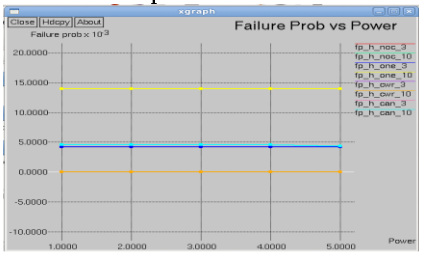

Figure 5: Failure Probability vs. Power.

Figure 6 shows effect of transmission range on Energy and Figure 7 shows transmission range vs. throughput. Considering different power transmission level that corresponds to different transmission ranges between 50m and 250 m, with fixed packet loss probability = 0.2. Figure 6 shows as the transmission range increases, the noise power increases, the contention increases which increase the retransmission of control and data packets, and all in turn, increases the total energy consumption. Only disjoint-paths scheme has larger energy consumption than our protocol.

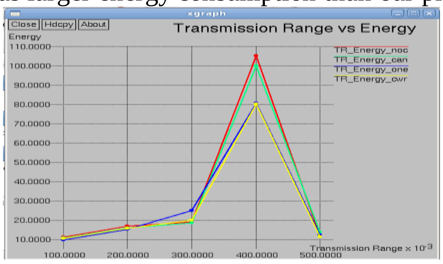

Figure 6: Transmission range vs. Energy

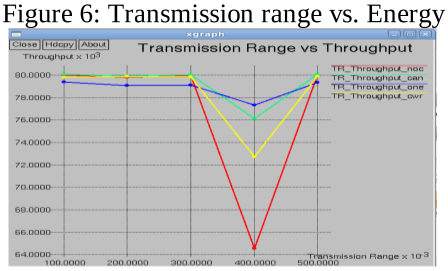

Figure 7: Transmission range vs. throughput

From figure 7, it can be analysed that as the transmission range increases the average number of hops in a path from source to sink decreases. When the *h* decreases, the difference in the failure probability between our protocol and the disjoint-paths scheme also decreases. This leads to a smaller difference in the capacity between the two schemes. When the network becomes a 1- or 2-hop network, there is no difference in the capacity between the two schemes. The capacity of the CAN protocol degrades with an increase in the transmission range. Thus higher energy is achieved in our Cooperative transmission protocol than disjoint paths scheme and One–path scheme and CAN protocol.

V. Conclusion

By analysing different parameters such as failure probability, transmission power, transmission range and energy consumption for cooperative transmission protocol and other cooperative and non-cooperative schemes, it can be shown that the total energy consumption can be considerably reduced by using cooperative factors of the our Cooperative transmission protocol than the compared schemes. With consideration of achieved results of end-to-end robustness of the protocol to data-packet loss, capacity and energy consumption we can say that longer lifetime of Sensor network will be achieved for cooperative transmission protocol.

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**Ms. Pallavi H. Chitte**, Postgraduate student, Terna college of Engineering, nerul, Navi Mumbai, has been doing the research work in wireless cooperative network.

. **Mr.D.K.Chitre** has been working as Associate Professor and Head of Department in Computer Engineering Department, terna college of Engineering, nerul, Navi Mumbai, has done research work in networking area.