An Energy Efficient Position Based Adaptive Real-Time Routing protocol for WSNs

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***Abstract*—Devices for Wireless Sensor Networks (WSN) are limited by power and thus routing protocols should be designed with this constrain in mind. This paper presents and evaluates an Energy Efficient Position Based Adaptive Real-Time Routing protocol (EFPBARP) as a novel, real-time, position based and energy efficient routing protocol. EFPBARP is a lightweight protocol that reduces the number of nodes which receive the RF signal using a novel Parent Forwarding Region (PFR) algorithm. EFPBARP as a Geographical Routing Protocol (GRP) reduces the number of forwarding nodes and thus the traffic and packet collision in the network. A series of performance evaluations through Matlab and Omnet++ simulations show significant improvements in network performance parameters and total energy consumption over CTP and Directed Flooding Routing Protocol (DFRP).**

Keywords:CTP; GRP; VNP; DFRP; EFPBARP.

I. Introduction

The main duty of Wireless Sensor Network (WSN) as a distributed computing network is collecting data from a large number of nodes that have the capacity to sense the environment, process data and also communicate over a short range. WSN applications collect data from wireless sensors and an appropriate routing protocol could help them to achieve scalability and improve performance. Data collection protocols can form planner or tree topology that could be in cluster or mixed data collection form. Energy eFficient Position Based Adaptive real-time Routing Protocol (EFPBARP) is one of the many-to-one routing protocols which is based on spanning tree method [1] [2]. EFPBARP establishes at least one data collection tree with a sink as the root node in the topology. All data which is produced by sensors are forwarded to the root node. Each node is not only responsible for sending its own data but also for relaying other's data so that they cover more distance to root node [3] [4] [5]. Trickle algorithm [6] optimizes the overhead cost and makes the routing protocols more flexible. The control protocol packets are sent based on changes in topology and if there is no change in topology, the interval times (duration) between when updates are sent is increased with a resulting decrease in the number of control packets. It also makes routing protocols react quickly and be adaptable to any changes in topology and if any change in topology is sensed then the interval time is reset to minimum in order to update the topology very quickly [7].

EFPBARP enhances greedy forwarding by considering congestion and packet delivery information when looking the best path to the destination. EFPBARP uses a mechanism for choosing a parent that it is based on Surface Distance (SD) value of each neighbour that chooses the best possible parent between existing qualified neighbours. EFPBARP uses a new mechanism to make it more energy efficient than other existing algorithm. The proposed protocol uses a unique restricted Parent Forwarding Region (PFR) based on the algorithm that limits the number of nodes that receive the packets. It decreases the Radio Frequency (RF) range to the minimum to cover the nodes parent only and for this reason other nodes do not consume energy to receive the signal and retransmit them. Geographical Routing Protocols (GRP)s make all nodes able to learn more about its location and also the position of neighbours and the sink. GRPs could make decisions with better performance in real-time and dynamic scenarios. GRPs decrease the overhead of the protocols significantly and makes them more efficient [8] [9] [10].

In this paper EFPBARP as a Two Dimensions Coordinate System (2D), real-time and geographical routing protocol has been proposed that provide a soft real-time capability for an effective heuristic solution for void node problem or hole problem. The Void Node Problem (VNP) or hole problem is called to a situation when a packet arrives at a node that does not have any neighbour to forward the packet toward the sink. The proposed protocol also uses a unique restricted PFR based algorithm that limits the number of nodes that receive the packet.

This paper is organized as follows: section II describes previous works and section III shows the EFPBARP design details and system model. Evaluation and results from simulations come in section V and finally conclusion is provided in section VI.

II. Related Works

ICTP [11] uses of both long path with good link quality and short path with bad link quality. It may decrease the reliability but it improves efficiency to avoid congestion. They have shown that the energy consumption in ICTP is less than CTP in same scenarios based on reducing possibility of congestion. BCTP [12] is balanced version of CTP that enables the network to avoid the heavy traffic nodes. It uses average transmission rate as a metric. BCTP has been evaluated by a test-bed and the results show that the load in hot spots drops by 61.9%. RAP [13] is a real-time GRP which uses the velocity of each packet as a gradient to deliver the packets. Each velocity is calculated based on the distance to the destination and its delivery deadline. The packets with higher velocities can be sent earlier than packets with lower velocities. However, this protocol does not provide any guarantee in end-to-end real time delivery. EDF [14] provides a real-time decentralized scheduling that guarantees the end-to-end delivery but it needs a priori defined schedule that is not feasible in most of WSNs applications. SPEED [15] is a real-time GRPs that uses neighbour information to estimate distance in routing protocol. SPEED lets each node decides which neighbour be the next hop forwarding node and in case of not existing any suitable node in neighbours, the node with the lowest miss ratio is used for forwarding the packets. MMSPEED [16] is an enhanced version of SPEED that focuses on reliability levels and multiple timelines. It uses resources with better performance than SPEED. RTLD [14] is a real-time routing protocol with load balancing based on link quality, packet delay and remaining power in the next hop neighbours. All the above mentioned protocols are based on 2D coordinate systems and need neighbour information to decide about next hop to forward the packets.

III. Design

A. Motivation

WSN consists of small devices for while energy consumption is a vital key. Any protocols that are used have to be energy aware. EFPBARP is a lightweight, simple reliable, efficient, best-effort, many-to-one routing protocol. Whereas the foundation for sensor applications could work on top of the network layer. Decreasing the number of nodes that receive unrelated signals decreases the number of retransmissions packets and also could save energy. Energy in a transponder is based on the range of the coverage by RF, the energy consumed in transponder is being proportional to the square of the RF coverage range. Any reduction in RF transmission range could save significant energy in wireless nodes [17].

B. EFPBARP

The proposed protocol has three main functionalities, parent selection that selects the best parent from the qualified neighbours of the node, location management that calculates the position of each node and the minimum radius of RF range and the VNP handling that avoids to forward the packets toward the hole or dead end. It is assumed that the nodes are deployed in a static scenario in a uniform randomly distributed manner. All nodes are in the same spherical transmission range and they are identical and every node knows its own location. The location of each node is represented in a Cartesian coordinates system (X,Y) which can be obtained from GPS module. The GPS module calculates the position of each node and it will be used only at the time of deployment and after that it will be switched off to save energy [18], [19]. The goal of the proposed protocols is to minimize the RF range based on parent location. After parent selection in PFR, the position of parents is sent to its entire child. PFR technique in EFPBARP uses the position's data to minimize the RF range. The RF range is calculated in location management phase and the transponder of the node set the transponder power to cover only the minimized RF range that is calculated based on node and its parent locations.

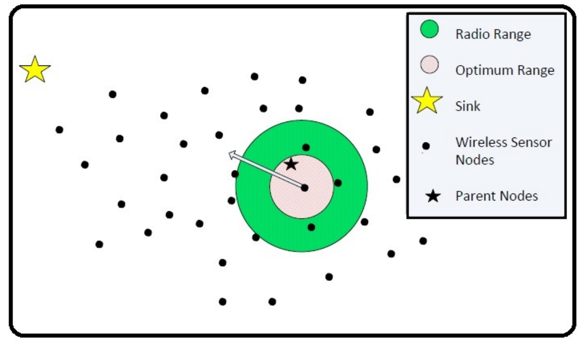


Fig. 1. Optimum Transmission Rang

1) Parent Selection in EFPBARP: A few nodes in the network advertise themselves as sink. Other nodes in the network form a tree network topology and send data toward these root nodes. Each node chooses the path to root by selecting the next hop based on a routing gradient [11]. EFPBARP uses Surface Distance (SD) as its routing gradient. Each node is labelled as a Minimum Root Distance (MRD) value. Roots MRD value is 0 and others nodes' value is calculated by formula 1:

$$Node(MRD) = Parent(MRD) + Link(SD) \quad (1)$$

$$Link(SD) = \sqrt{(Xp - Xn)^2 + (Yp - Yn)^2} \quad (2)$$

Where $Link(SD)$ denotes to surface distance of node p and n and (X_p, Y_p) denotes to position of parent and (X_n, Y_n) denotes to position of the node. Each node selects its parent from a group of its qualified neighbours that have already advertised their MRD values. The neighbour that is selected as the node's parent is the neighbour with the least MRD value. Location management phase is one of the key factors in EFPBARP. The Parent Forward Region (PFR) is calculated in location management phase to ideally contain minimum forwarding nodes to limit the number of retransmitting nodes in group of one hop neighbours. In PFR, the parent location denotes as (Xp, Yp) and the node location denotes as (Xn, Yn).

Figure 2 shows the flow chart of EFPBARP algorithm. It shows for sending each packet it checks the status of parent and if the protocol needs to go to parent selection mechanism then it selects a new parent and then set the RF to a range that cover only this new parent.

The parent location information is provided to nodes during the parent selection mechanism. Then the neighbours' node calculates the distance between nodes to its parent. In forwarding management phase to avoid redundant packet transmission in the network, the transponder power set to cover only the Minimum Transmission Distance (MTD).

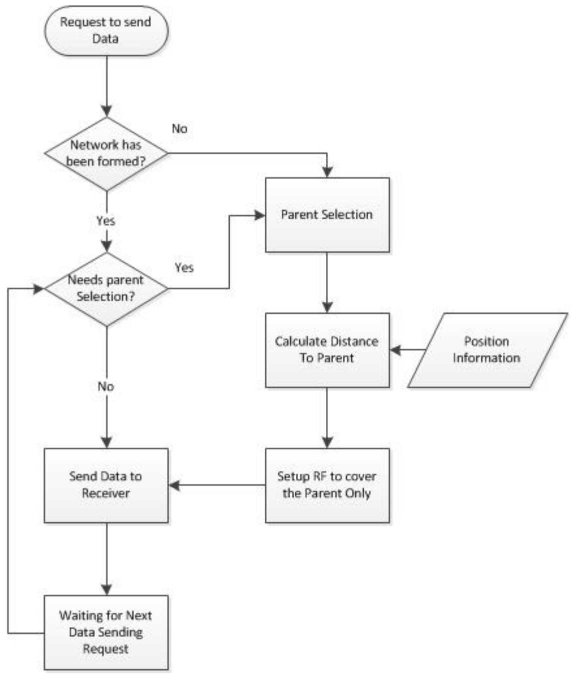


Fig. 2. EFPBARP Algorithm

$$MTD = \sqrt{(Xp - X)^2 + (Yp - Y)^2} \quad (3)$$

Where (X_p, Y_p) denotes to position of parent and (X, Y) denotes to position of the node.

2) Rainbow Mechanism in EFPBARP: In this section the Rainbow mechanism has been considered and it has been demonstrated how it is used in EFPBARP to avoid dead ends routes. The principle of Rainbow is forward the packets toward the sink. In this mechanism every node has a colour code based on how far is from the sink. The order list of colour shows that how by selecting the next relay node could travel toward the sink. Let $C_k(i)$ the colour code of node i and node i will forward only to next relay nodes with colour code equal to C_{k-1} or C_k. It will guarantee that the packets travel toward the sink and it avoids to send the packets toward dead end routes [11]. Figure 3 shows how the nodes select their parents based on Rainbow mechanism. Each node selects its parents with its colour code or with colour code in order to be close to sink.

The colour code in each node is calculated based on a counter. The rainbow counter is the number of received packets from the sink. Any node with higher value of this counter shows that it is closer to the sink with other nodes with lower value.

3) Loop avoidance in EFPBARP: EFPBARP uses a detection mechanism during the data packet transmission to validate the routing path and topology. This mechanism makes EFPBARP avoid loops by checking the previous $N(l)$ nodes that packet comes through. If the current node is in the list of $N(l)$ last nodes, a network loop will occur and reconsidering

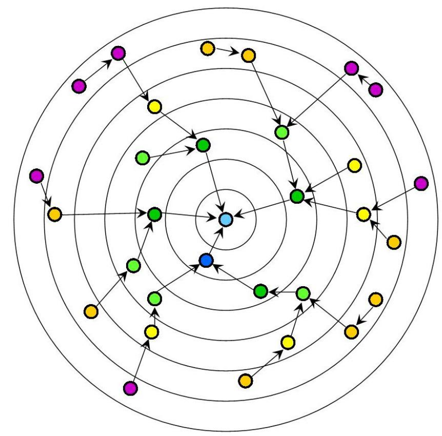


Fig. 3. Rainbow colouring technique

the topology will be needed to put this in order. EFPBARP uses a detection mechanism during the data packet transmission to validate the routing path and topology. This mechanism makes EFPBARP to avoid loops by checking the last $N(l)$ nodes that packet comes to this node through. $N(l)$ will setup in the initiate stage.

IV. SYSTEM MODEL

The system evaluation has been performed through massive simulations. Omnet++ has been used as WSN simulator and Matlab has been used for simulating the energy model. Each scenario runs more than 20 times to collect the reliable results with confidence intervals of 0.95.

A. System Channel Model

The simulations run on a field area of $200 * 200$ meters and the radio feature CC2420 [20] has been used as radio module that is working on IEEE 802.15.4 standard [21]. Simulations have been run from 18 seconds up to 3000 seconds. The variety of radio channel has been set up by "Wireless Channel Sigma" that are 0,1,3,5. Wireless Channel Sigma shows the standard deviation of communication channel diversity. The received signal strength at a wireless node in real scenarios does not only depend on distance from the transmitter but also on shadowing effects. The sigma parameters represent the random shadowing effects in the wireless channel parameters. Radio Collision Mode has been selected to 1 that puts more collision than normal. The application for these scenarios is "CtpTesting" that has been designed to test Collection Tree Protocol (CTP) functionality. It sends 5 packets every second with the payload of 150 bytes.

B. Energy Consumption Model

The energy consumption models are compared by a study in [22] that shows the components that consume energy in WSNs. In this paper, it has been assumed that the power energy that is consumed is mostly derived by the RF module for transmission signals which are involved sending and receiving packets in wireless sensor nodes. Following the [23] [24] [25] researches, the mathematical model for energy consumption by transmitting and receiving packets per bits of each sensor nodes are calculated as following. The energy consumption in RF module in receiver is given as:

$$E_{Rx}(k) = E_{elec} \times k \tag{4}$$

Where E_{Rx} is the energy consumption in receiver node, E_{elec} is the energy required to process one bit in the electronic modules and k is the length of message (bit) and the energy consumption in transmitter RF module is given as:

$$E_{Tx}(k, d) = E_{elec} \times k + E_{amp} \times k \times d^2 \tag{5}$$

Where E_{Tx} is the energy consumption in transmitter node, E_{amp} is the energy required to transmit one bit in the RF module and k is the length of message (bit) and d denotes the distance between transmitter and receiver measured in meter.

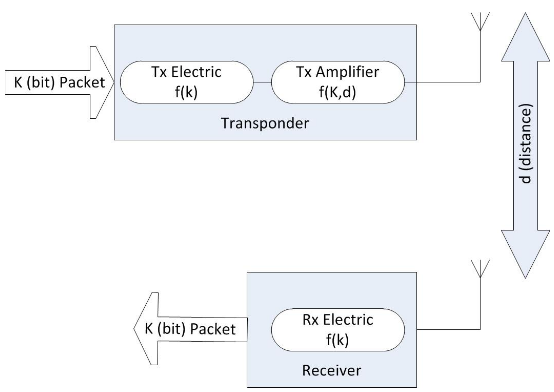


Fig. 4. Energy Model System

V. Performance Evaluation

The results have been collected in different scenarios in different number of nodes in the field, RF range and the number of packets with confidence intervals of 0.95. In this experience CTP, EFPBARP and Directed Flooding Routing Protocol (DFRP) have been compared. Table II shows the parameters of simulations. Omnet++ has been employed as simulation to measures Packet Delivery Ratio (PDR) and delay. End-to-end delay has been measured in all three routing protocols and also PDR. Matlab has been used for simulating the energy model. The total energy, number of retransmitted messages and also numbers of received messages in different scenarios have been investigated in this research. The scenarios contain different wireless nodes in the field, different RF range and also different number of messages.

Figure 6 shows the number of received and retransmitted messages and also the total energy consumption in different radio frequency ranges in the field.

The application layer measures the level of packet latency in (ms). Figure 7 shows the packet delivery delay level in three routing protocols: CTP, EFPBARP and DFRP. The results show EFPBARP has better performance than CTP and also DFRP in term of packet delivery delay. EFPBARP has

TABLE I
Omnet ++ Simulation Parameters

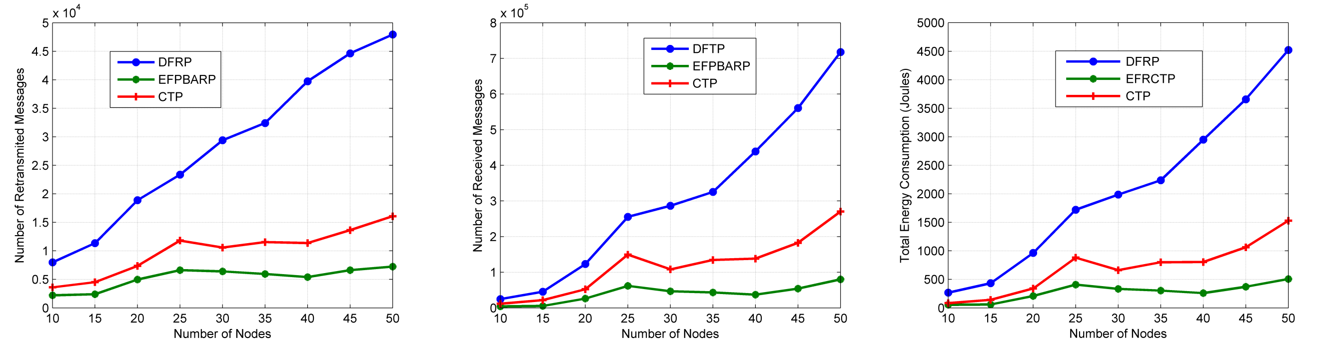
Simulation Parameters	
Number of nodes	10,20,..,100
Node Deployment	Random
Field Area	200 X 200 (m)
E_{elec}	50 nj/bit
E_{amp}	100 $pj/bit/m^2$
Simulation time	18-3000 Sec
Wireless Channel Sigma	0,1,3,5
Radio Parameters	CC2420
Routing Protocols	CtoNoe, EFPBARP, DFRP
Application	CtpTesting
App Packet Rate	5
APP Payload	Constant 150 bytes
Max Frame Size	2500 byte
Radio Tx Power	-5 dBm
Radio Collision Model	1

delivered in average about 34% of packets in less than 20 ms instead of CTP that it delivered about 25%. It is obvious that EFPBARP has better performance than CTP in term of packet delivery delay time.

Application layer also measures the percentage of packet delivery ratio that it shows the amount of packets that successfully received in their destinations. Figure 8 shows the packet delivery ratio in three routing protocols. The results show CTP and EFPBARP have the same result in term of packet delivery ratio in scenarios that wireless nodes are less than 70 nodes. When the number of nodes in the fields increases to 70 nodes, it is obvious that EFPBARP could deliver more packets than CTP. In scenario with 100 nodes in the fields, packet delivery ratio in EFPBARP is 54% and CTP could manage to deliver around 46% of the packets. Figure 9 shows the number of retransmitted messages in different number of messages scenarios. In average the EFPBARP retransmits messages 81% less than DFRP and 49% less than CTP. Figure 10 shows the number of received messages in different number of messages scenarios. In average, the EFPBARP retransmits messages 84% less than DFRP and 62% less than CTP. Figure 11 shows the total energy consumption in different number of messages scenarios. In average the EFPBARP consumed energy 85% less than DFRP and 59% less than CTP.

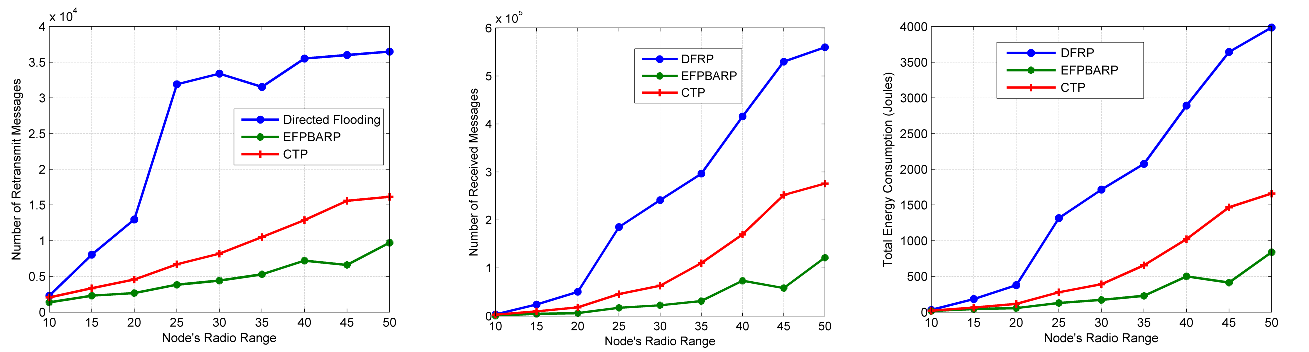
VI. Conclusion

This paper proposed EFPBARP as an Energy Efficient Position Based Adaptive Real-Time Routing protocol. EFPBARP performs with more accuracy by using a new parent selection and Rainbow mechanisms to choose the parents with more accuracy. It also employs techniques to avoid loops in the topology. EFPBARP as a GRP decreases the RF range in each node by reducing the number of nodes which receive the signal, using a new PFR technique. Nodes reduce the RF range to cover their parents only and not any nodes with further distance in location management phase and PFR. A massive simulation on EFPBARP shows a significant improvement in performance regarding energy consumption compared to



(a) Retransmitted Messages and Number of Nodes (b) Received Messages and Number of Nodes (c) Total Energy Consumption and Number of Nodes

Fig. 5. EFPBARP, CTP and DFRP in different number of Nodes scenarios.



(a) Retransmitted Messages and Radio Range (b) Received Messages and Radio Range (c) Total Energy Consumption and Radio Range

Fig. 6. EFPBARP, CTP and DFRP in different Radio Range scenarios.

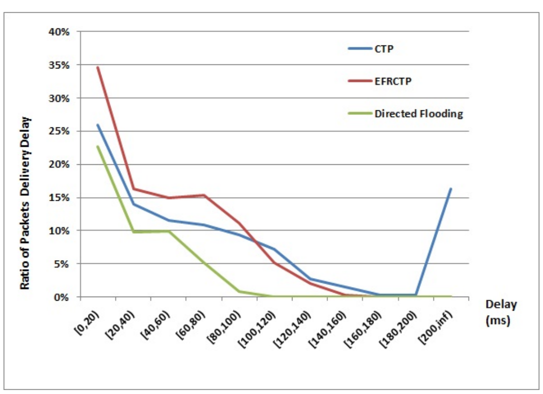


Fig. 7. Packet delivery ratio based on CTP, EFPBARP and DFRP

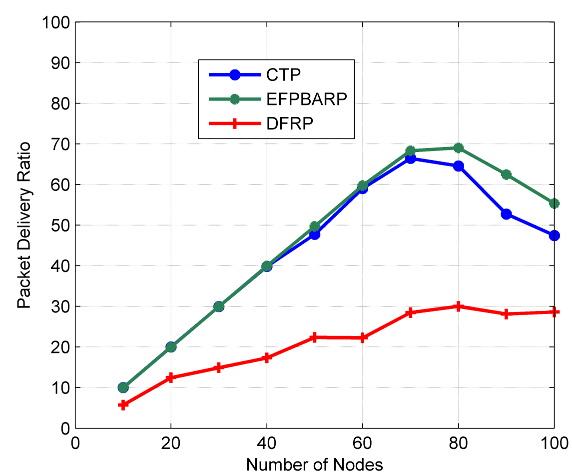


Fig. 8. Packet delivery ratio based on CTP, EFPBARP and DFRP

CTP and DFRP in different scenarios. EFPBARP has showed a performance improvement in packet delivery parameters. EFPBARP shows that it could save more than %80 of the total energy consumption in the network by using the special technique in PFR. It also provides better performance in busy and noisy environments in terms of packet delivery time and the ratio of successful packet delivery.

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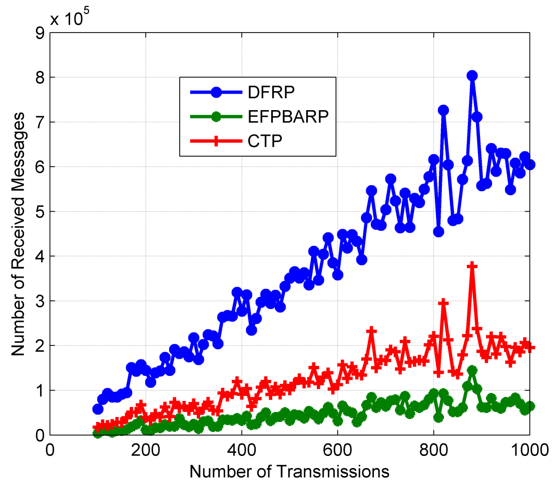

Fig. 9. Number of Retransmitted messages in EFPBARP, CTP and DFRP

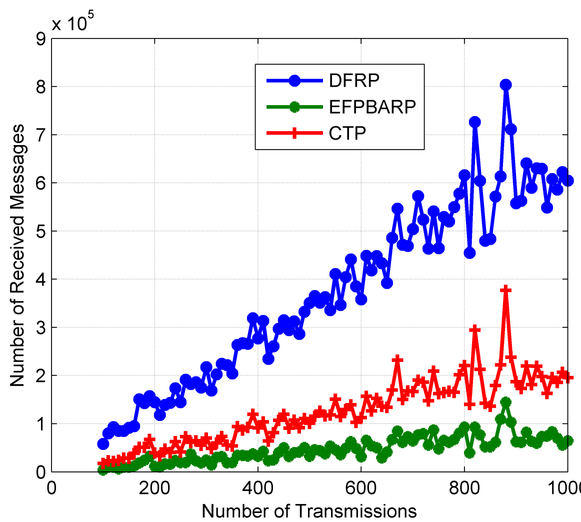

Fig. 10. Number of Received messages in EFPBARP, CTP and DFRP

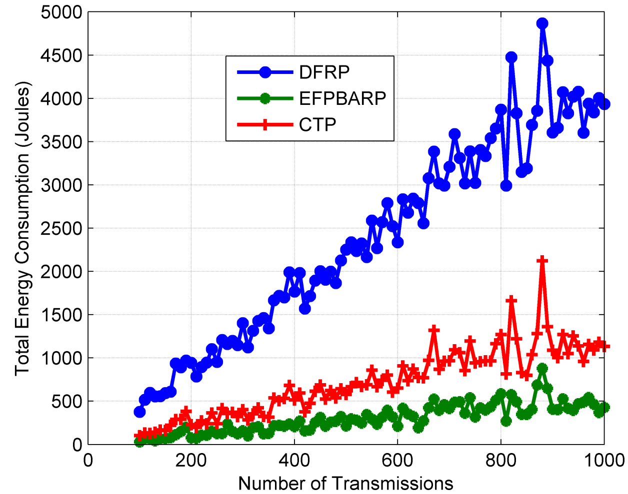

Fig. 11. Total Energy Consumption in EFPBARP, CTP and DFRP

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