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A MAC based On-Demand Converged Broadcast Scheme for Congestion Avoidance in Wireless Sensor Networks

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Abstract: Wireless Sensor Network (WSN) is an integrated collection of independent sensor devices that gather information from the environment, manipulate on them and relay the same to a common node or base station. There are several factors that affect the sensor performance that serves as a major design and deployment issue consideration at the time of designing these networks. Congestion in these networks leads to improper resource utilization and retard in performance enhancement. We address the problem of earlier energy drain due to improper congestion management caused by broadcast storm. MAC based On-demand Converged Broadcast (M-OCB) is a neighbor aware opportunistic technique to minimize link flooding in WSN so as to minimize congestion and early energy drain. This method bridges the gap between energy and congestion by distinguishing neighbor selection and broadcast process as distinct integrated approach. The proposed technique is analyzed using simulations. The simulation results confirm that the proposed technique performs better on throughput, delay, energy, drop and congestion ratio.

Keywords: Congestion Estimation, Energy Efficient Routing, MAC Broadcast, Neighbor Aware Routing, Periodic Broadcast

1. INTRODUCTION

Wireless Sensor Network (WSN) applied for large applications face different design challenges due to its resource constraints. Resource constraints include energy, computational capability, communication mode, area of deployment and so on. A sensor node deployed must be capable for serving a long run without any lag. The major design issue is concerned about utilizing energy in a conservative method. This requires hardware, operating system and operational protocols that aid the purpose. Transmission energy constitutes the major part of the overall energy utilization that varies as the distance between the WSN devices. There are distinct design parameters that vary according to the application considered namely: network lifetime, load handling capability, support for scalability, clustering, etc. Besides, the operational protocols also constitute an appreciable part of design issue consideration. An ideal protocol must able to handle complex communication so as to exchange information in an efficient manner, without the impact of energy constraint.

Low Energy Adaptive Clustering Hierarchy (LEACH) is a familiar cluster based routing protocol that achieves energy efficiency in WSN. Header selection in LEACH is based on single constraint that is not sufficient to make the protocol effective over multi constraint network like WSN [1, 2]. Contrarily, another challenge is congestion that is to be met while relaying volumes of sensed information to a sink node. Congestion hinders reliable transmission by increasing packet loss. In a densely populated WSN, congestion leads to delay and earlier energy drain as the data flow in the network is considerably high [3].

Solutions proposed by the researchers in the concentrate in throttling the network's incoming traffic flows. Simply, the solutions focused in controlling network traffic other than handling it effectively [4-6]. The authors of [7] proposed DRINA routing algorithm for improving aggregation

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precision with minimal energy consumption. The number of control messages generated and exchanged by DRINA is less. An multipath cost based weighted path selection protocol WEAMR [8] is proposed to improve the handling of network traffic under balanced transmission. An energy and weight based path selection protocol MICRO [9] is proposed to improve the network efficiency in terms of energy and latency. This protocol effectively bridges the gap between energy level of the node and energy utilization.

Sharma and Kumar [10] introduced a clustering based approach to minimize energy consumption despite network data. The header selection is based on distance and energy factors that are decided upon a fuzzy function. Congestion Aware Routing [11] protocol classifies network regions as traffic intensive and less congested zones so as to relay information.

Kumar et al., [12] proposed a self-organizing WSN system that can able to achieve scalability based on co-operative communications. The authors in [13] proposed a congestion control algorithm that works independently. The algorithm is designed such that the changing network topology and node addressing phases have lesser impact over network traffic. The authors in [14] proposed an agent based routing scheme in which the deployed agents are responsible for searching new routing paths for transmission. The agents aim at achieving energy efficient data relaying. Shakshuki et al., [15] proposed a multi agent system for data gathering and decision making processes. The authors in [16] proposed Traffic aware and Energy efficient Routing (TER) with two independent functions of energy and traffic, to improve network throughput and to minimize energy consumption.

2. PROBLEM DEFINITION

Resource constraint nature of the WSN makes it feeble for aiding support for large scale applications. In a densely populated network, sharing traffic information in forehand increases network complexity of sharing control messages and broadcast storm retards the functions of the sensor node. This leads to performance degradation. We propose a co-operative MAC based Opportunistic Converged Broadcast (M-OCB) technique to select nodes based on interest or replacement. The proposed MAC based opportunistic broadcast aids network performance improvement based on throughput, delay, energy utilization and congestion.

Network Model

We deem a network consisting of $\{n_1, n_2, \dots, n_n\} \in N$ nodes that are provisioned with same initial energy(E_0). The active transmitting source nodes relay data to a common node called sink node(S_n). The sink node is present either at one-hop or multi-hop away from the source node. The nodes possess different energy consuming models for transmission and reception.

Energy Model

A node drains it energy for transmitting and receiving data. The energy consumed by a node (E_c) is given by equation (1)

$$E_c = E_{tx} + E_{rx} \quad (1)$$

Where,

E_{tx} and E_{rx} are the energy spent by a node for transmission and reception. Transmission energy and reception energy is given by (2) and (3) respectively

$$E_{tx} = d_{tx} \times e_{tx} \times t_{tx} \quad (2)$$

Where,

d_{tx}, e_{tx} and t_{tx} are the rate of data transmission, energy spent on that transmission and transmission time.

$$E_{rx} = d_{rx} \times e_{rx} \times t_{rx} \quad (3)$$

d_{rx}, e_{rx} and t_{rx} are the rate of data received, energy spent for reception and data reception time.

3. CO-OPERATIVE MAC BASED OPPORTUNISTIC CONVERGED BROADCAST TECHNIQUE

The proposed Co-operative MAC based Opportunistic Converged Broadcast Technique is of two phases:

(i) On-demand Broadcast and
(ii) Selective Neighbor Routing

The process of co-operative MAC based opportunistic converged broadcast technique is illustrated in figure 1.

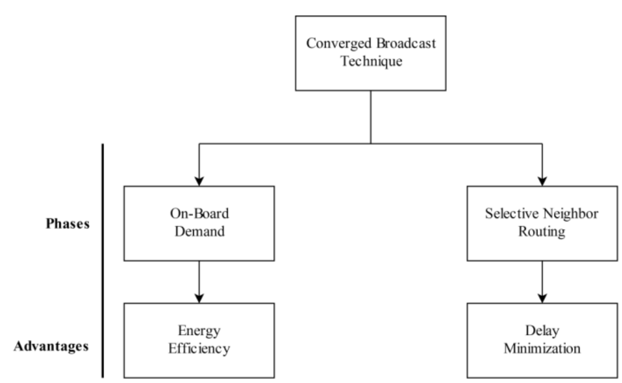

Figure 1. Converged broadcast Technique Process

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On-Demand Broadcast

The source node initiates broadcast to find its neighbors to relay packets to the sink node. The conventional routing process is by selecting neighbors based on shortest distance and the source pursues the same. On-demand broadcast is initiated when a link failure or route error occurs at the time of relaying packets. Initially, the nodes are said to be in active state where in a restricted set of nodes relay information and the other nodes are moved to idle state [duty cycle ref]. This helps to conserve node energy by preventing the node from being an lively listener to all the messages in its path. When a route failure occurs, the sensor node initiates a route error message to its predecessor node. The active transmitting node then initiates a rerouting so as to rectify the routing error and to pursue efficient transmission.

The source node other than waking up all the sleep state nodes, selects a particular node to support rerouting. The source initiates a MAC based broadcast to a single node with the forehand information of the trans-receiver physical address. By minimizing the number of control messages, broadcast storm is minimized and the energy utilized for the overhearing broadcast is conserved. The time of the broadcast (t_b) occurrence is computed using equation (4) [traw pg 5 left]

$$t_b = \frac{t_i}{t_s} \tag{4}$$

Where, t_i and t_s are the initial broadcast time and sampling time interval. As the network is concentrated towards congestion, the upper bound of the network requirement is given by equation (5)

$$d_{rx}(t_s + d_{tx}) \leq 1 \tag{5}$$

The active network nodes must satisfy (5) so as to maintain balanced energy utilization. If the upper bound exceeds 1, then the network is said to be congested. An idle node must wake up from its state at the time of on-demand broadcast so as to pursue the left out transmission. The optimal time through which the node remains in idle state is given by equation (6)

$$t_{idle} = 1 - t_i - t_{tx} - t_{rx} \tag{6}$$

The next cycle of transmission from the selected node starts from optimal time(t_{idle}). This time need not be same for a number of nodes in a same region. As the optimal idle time is not same for all the nodes in the network, the number of concurrent transmission is less. This minimizes two factors of the network:

a. Overhead caused due to control messages
b. Improper data relaying with traffic

(i) Selective Neighbor Routing

Selective Neighbor Routing describes the process of intermediate node selection based on the resource constraint and link utilization at the time of MAC broadcast. We consider two factors for neighbor selection at the time of MAC broadcast initialization: Node's residual energy (E_R) and its lifetime(N_T). The node's residual energy is computed using (7)

$$E_R = E_0 - E_c \tag{7}$$

Node lifetime is computed using equation (8)

$$N_T = \frac{E_0}{E_c} \tag{8}$$

For a node to be selected as intermediate, the node must meet the following constraints viz., E_R of the node must be higher than the half energy level of the node. Half energy level of the node is defined as the state of energy that is equally half of the nodes' initial energy. Mathematically, half energy (E_h) of a node is expressed as in (9)

$$E_h = \frac{E_0}{2} \tag{9}$$

The constraint can be expressed $E_R > E_h$ for a node to be selected as intermediate.

Secondly, the lifetime of a node must be greater than the lifetime of the other node that is present within the transmission range of the source node. Let 'i' and 'j' be the nodes that are present within the range of the source node. Let us consider i^{th} needs to be selected as the next intermediate, then

$$N_T(i) > N_T(j), \forall\, t \tag{10}$$

Equation (10) is the second constraint that the node needs to meet at the time of neighbor selection.

The selected neighbor will be relayed with the next sequence of packets until the nodes' lifetime or its residual energy constraint fails as per the dual constraints. This helps to improve earlier detection of link failures due to energy drops and also prevents a single node to be burdened at the time of link errors. Therefore, the nodes in the network are prevented from handling large volumes of data despite transmission or node drop outs. This minimizes network delay due to retransmissions and also aids minimizing control messages flow.

4. RESULTS AND DISCUSSION

The proposed Co-operative MAC based Opportunistic Converged Broadcast Technique performance is analyzed using network simulation. The proposed technique is analyzed for the network metrics like: Throughput, End-to-

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End Delay, Packet Drop, Congestion Ratio and Energy. The simulation parameters are presented in table I.

Table I. Simulation Parameters

Simulation Parameters	Value
Network Region	1000 X 1000
Sensor Nodes	50
Routing Protocol	DSR
Initial Energy	10J
Broadcast Range	250m
Data Rate	250bps
Simulation Time	100s

5. SIMULATION RESULTS

We evaluated out proposed M-OCB using the following metrics that are compared with TER [16] and Agent based Routing in WSN [14].

Throughput

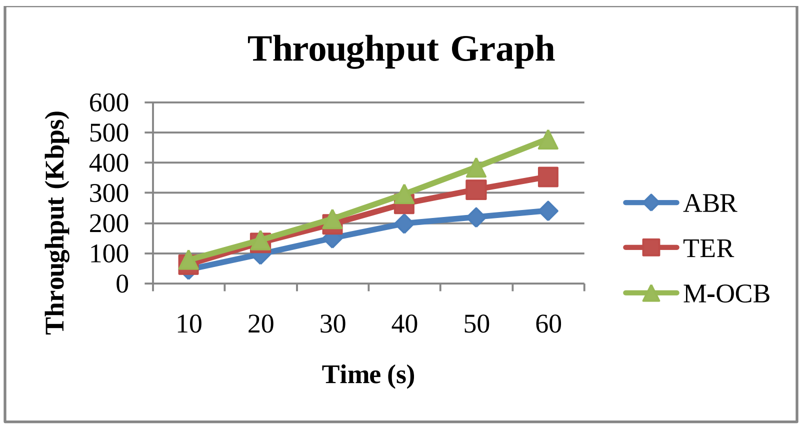

Figure 2. Throughput Graph

The proposed M-OCB minimizes congestion by an on-demand MAC that saves network being populated at all time. This minimizes the number of transmissions under congestion. Therefore, the number of relayed packets is streamed with less traffic that results in higher throughput (Figure 2) compared to TER and ABR.

End-to-End Delay

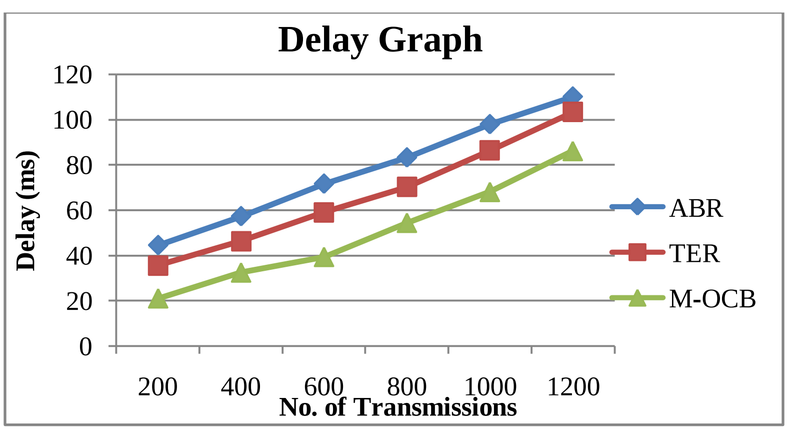

Figure 3. End-to-End Delay Graph

Figure 3 illustrates the delay observed in the network, comparing the delay of M-OCB with TER and ABR. In our proposed method, the number of flows and transmissions need not be paused for a specific time interval or it does not wait for the fore hand traffic information. Besides, the detouring process needs lesser time interval for the nodes to be updated. This results in lesser time delay for the packets to be delivered at the sink node.

Packet Drop

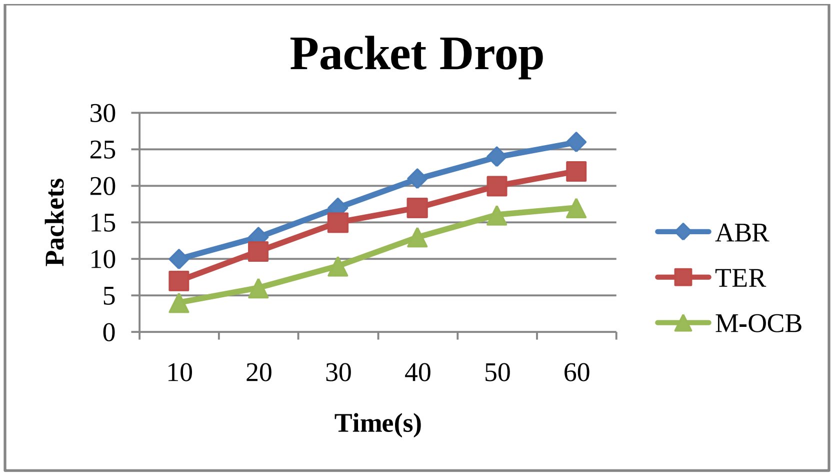

Figure 4. Packet Drop Graph

The comparison of packet drop compared between ABR, TER and M-OCB is illustrated in figure 4. M-OCB minimizes the rate of congestion at the time of relaying by initiating on-demand MAC broadcast. This prevents unnecessary overhearing of nodes to relay packets when they are equipped with other transmissions. Therefore, congestion occurrence is less in M-OCB unlike the other prior information broadcast methods. As congestion occurrence is less in the network, the number of dropped packets is comparatively low.

Congestion Ratio

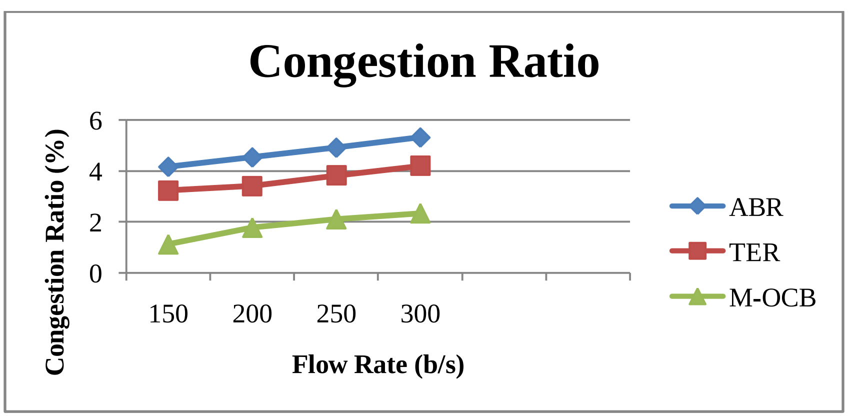

Figure 5. Congestion Ratio Graph

As the flow rate in the network increases, the number of transmitting bits in a single link increases, resulting in congestion (Figure 5) after an observed time interval. Using on-demand opportunistic broadcast and MAC based specific neighbor selection, the quantity of links being overloaded is distributed among the available nodes. This minimizes the possibilities of a link being congested.

Energy

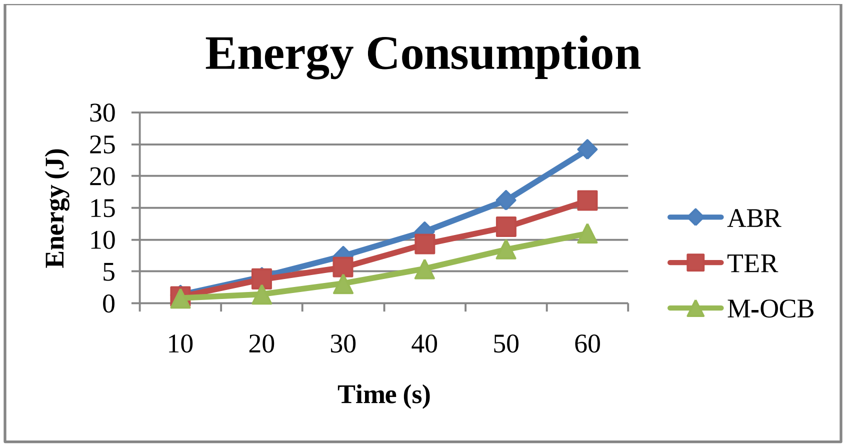

Figure 5. Energy Graph

Figure 5 illustrates the energy consumption of the network observed for M-OCB, TER and ABR. In our proposed M-OCB, the number of control messages and periodic broadcast are less that requires a lesser energy consumption. Moreover the number of retransmitting packet count is less that needs no additional expense of transmission energy. Therefore the overall energy consumption of the network is less when compared to ABR and TER.

6. CONCLUSION

Energy optimization in resource constraint WSN is tedious for which an acceptable tradeoff is required. To address the issue, we have proposed a convergence based MAC broadcast scheme that selects nodes based on interest so as to minimize unnecessary broadcast storm. The proposed M-OCB excels par better than the existing approaches by minimizing energy consumption by 31.78% and 54.4%, delay by 16.59% and 21.7%, drop by 22.72% and 34.61%, congestion ratio by 1.86% and 2.98% when compared to TER and ABR respectively. M-OCB improves throughput by 26.07% and 49.56% when compared to TER and ABR respectively. The process is planned to extend its support by integrating QoS aiding scalable algorithms that can serve resource constraint emergency real-time applications.

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