Lifetime Analysis Using Encoding Technique in Wireless Sensor Network

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ABSTRACT—
The significant challenge in Wireless Sensor network is to maximize the network lifetime through minimizing energy. The monitoring area close to the Sink node forms a bottleneck zone because of large traffic flow which limits the network lifetime in wireless sensor network. In this paper, we introduce an encoding technique for reducing energy consumption in the bottleneck zone. An efficient communication paradigm has been adopted in the bottleneck zone by combining duty cycle and encoding technique. Energy efficiency of the bottleneck zone increases because more volume of data will be transmitted to the Sink with the same number of transmissions. Hence the lifetime of wireless Sensor network is enhanced. Life time can be analysed by considering with two scenarios of single hop and multihop. The lifetime upper bounds have been analysed by combining duty cycle and encoding technique. The simulation results demonstrate the efficacy of proposed technique.

KEYWORDS
WSN-wireless sensor networks, duty cycle, encoding technique, network lifetime, Relay nodes, network coder nodes.

I. INTRODUCTION
Information gathering is a fast growing and challenging field in today’s world of computing. Sensors are tiny devices that are capable of gathering physical information like light, heat, motion of an object or environment. Wireless sensor network consist of autonomous sensor nodes that can be deployed for monitoring areas, such as, forests, fires, glaciers, deep oceans etc.[1][2] Sensor node is made up of four basic component namely sensing unit, processing unit, transceiver unit, power unit. The nodes can self organize themselves to form a multi-hop network and transmit the data to a sink. In an energy constraint WSN, each sensor node has limited power energy for which enhancement of network lifetime becomes a major challenge.

In a distinctive wireless sensor network, the network traffic meets at the sink nodes (fig1). There is a large amount of data flow near the sink. The area around the sink is known as the bottleneck zone. Heavy traffic load imposes on the sensor node near the sink node. The nodes in the bottleneck zone consume more energy, referred as energy hole problem. Failure of such nodes inside the bottleneck zone leads to wastage of network energy and reduction of network reliability.

Figure 1.Traffic flow, bottleneck zone and roles of sensors

The all-node-active condition is not practical for energy constraint WSN. The sensor nodes save energy by switching between active and dormant (i.e. sleep) states. The ratio between the time during which a sensor node is in active state and the total time of active/dormant states is called duty cycle. The duty cycle depends on the node density of the monitored area for better coverage and connectivity. Usually for a dense WSN the duty cycle of a node is very low.

A duty cycled WSN can be classified into two categories namely, random duty-cycled WSN [3] and co-ordinated duty cycled WSN [4]. In random duty cycle, the sensor nodes can be turned on and off independently in a random fashion. In co-ordinated duty cycle, the sensor nodes are coordinate among themselves through communication and
control message exchanges. However, it requires additional information exchange to disseminate the active/sleep schedule of each node. The random duty cycled WSN are simple to design as no additional overhead is required.

In this paper, we introduce an encoding technique to reduce the energy consumption in the bottleneck zone. This technique improves the capacity of an information network with better utilization of bandwidth. The encoding technique also improves reliability of the network. Hence the proposed encoding based communication paradigm which reduce the traffic load imposes on the sensor node and thereby increases the network lifetime.

II. UPPER BOUND OF NETWORK LIFETIME USING DUTY CYCLE

A. SYSTEM MODEL

A system is considered with two scenarios namely single hop and multi hop. In first scenario, choosing coder nodes uses a single hop to communicate with sink. In the second scenario, selecting nodes as coder nodes uses a multi hop to communicate with the sink. Consider 50 sensor nodes scattered uniformly in area A for single hop and 100 sensor nodes for a multi hop. The area A with a bottleneck zone B with radius D is shown in Fig. 1. All the N sensor nodes are duty cycle enabled (i.e. switching between active and dormant states). The nodes are named based on their roles in the network as shown in Fig. 1. In the zone B, the nodes are classified into two groups named based on their network, such as, relay sensor and network coder sensor nodes. The (active) relay sensor nodes (R) transmit data towards the sink. The (active) coder nodes (N) encode the raw native data which are coming from outside the zone B before transmission. The sensor nodes outside the zone B are marked as I and L in Fig. 1. The leaf sensor nodes (L) periodically sense data and transmit them toward the Sink. The intermediate sensor nodes (I) relay the data in the direction of the Sink S. In the bottleneck zone, the relay node scan communicate with the Sink using a multihop communication. However, the network coder nodes use a single hop to communicate with the Sink. The radius should be at least equal to the maximum transmission range of a sensor node, so that the data generated outside the bottleneck zone can be relayed through the zone Lifetime can also be analysed by selecting as coder nodes uses multi hop to communicate with the sink.

B. ENERGY CONSUMPTION MODEL WITH DUTY CYCLE

A sensor node consumes energy at different states, such as, sensing and generating data, transmitting, receiving and sleeping state. In this work, the radio model [6] has been modified for a duty cycle based WSN. Energy savings are done at the node level through switching between active and sleep states.

![Figure 2. State transition diagram of a node](image)

Energy consumption by a source node per second across a distance d with path loss exponent n is,

\[ E_{tx} = Rd(\alpha 11 + \alpha 2dn) \]

Where \( Rd \) is the transceiver relay data rate, \( \alpha 11 \) is the energy consumed per bit by the transmitter electronics and \( \alpha 2 \) is the energy consumed per bit in the transmit op-amp [6]. Moreover, the total energy consumption in time t (i.e. duration [0,t]) by a source node (leaf node) without acting as a relay (intermediate node) is,

\[ ES = t[p(\text{rses} + E_{tx}) + (1-p)E_{sleep}] \]

where \( E_{sleep} \) is the sleep state energy consumption of a sensor node per second, \( rs \) is the average sensing rate of each sensor node and it is same for all the nodes, \( es \) is the energy consumption of a node to sense a bit, the probability \( p \) is the average proportion of time t (in the duration [0,t]) that the sensor node devotes in active state. Thus, \( p \) is the duty-cycle. A sensor node remains in the sleep state with probability \( (1-p) \) till time t. The state transition diagram of a source node is shown in Fig. 2 (i.e. in the dotted rectangle). The energy consumption per second by an intermediate node which act as a relay is given by

\[ E_{txr} = Rd(\alpha 11 + \alpha 2dn + \alpha 12) = Rd(\alpha 1 + \alpha 2dn) \]

Where \( \alpha 12 \) is the energy consumed by the sensor node to receive a bit. Total energy consumption till time t by an intermediate (relay) node is

\[ ER = t[p(\text{rses} + E_{txr}) + (1-p)E_{sleep}] \]

The state transition diagram of a relay is shown in Fig. 2.
C. ENERGY CONSUMPTION AND UPPER BOUND OF NETWORK LIFETIME

Total energy consumption in the bottleneck zone are viewed as three parts, namely, energy consumption (i) to relay the data bits which are received from outside of the bottleneck zone (ii) due to sensing operation of the (relay) nodes inside the bottleneck zone (iii) to relay the data bits which are generated inside the bottleneck zone. A sensor nodes in the bottleneck zone may receive multiple copies of the same data bits transmitted from outside of zone B. So, the redundant bits (refer fig 3) which affect the network lifetime are transmitted inside the zone B.

Figure 3. Reception of redundant data bits by the boundary relay nodes in the bottleneck zone

III. UPPER BOUND OF NETWORK LIFETIME USING ENCODING TECHNIQUE AND DUTYCYCLE

Network coding or encoding technique is a methodology for enhancing a lifetime of a wireless sensor network. Network coding [7] was first introduced in a wired network to solve bottleneck problem and to increase the throughput. However, the broadcast nature of wireless network and the variety of links make a network coding more enchanting in wireless sensor network.

An Encoding layer (refer fig 4) include network coder nodes has enclosed all over the sink. The network coding layer is the most overloaded (vulnerable node) region of bottleneck zone. The coder nodes uses a single hop to communicate with the sink. There is a two group of nodes namely; relay nodes and network coder nodes. The nodes are named depending upon their network. A group of vulnerable nodes in the bottleneck zone transmit using encoding based algorithm. The other group of nodes in the bottleneck zone act as a simple relay nodes. These relay nodes forward the received packet towards the sink. The node follows the Algorithm-1 to process a packet.

Figure 4. XOR –network coding in the network coding layer of the bottleneck zone

ALGORITHM 1: Packet Processing (Pi) algorithm:
1. Pick a packet Pi from RecvQueue (Pi)
2. If Packet Pi ∈ForwardPacketSet (Pi) exit;
3. If Node n ∈EncoderNodeSet (Pi) continue;
4. If native (Pi) then
5. CN =XorEncode (Pi);
6. Node n transmits the coded packet CN to Sink
7. Insert the processed packet Pi to ForwardPacketSet();
8. Else
9. Discard (Pi);
10. Endif
10. Else
11. Node n acts as relay and transmits the packet Pi to the Sink;
12. Endif
13. Endif
14. If (RecvQueue () ≠ empty)
15. Goto step 1;
16. Else exit;
17. Endif

The functionality of network coding layer is to checks its role (refer fig 5). Whenever a node enter into the bottleneck zone. The network coding layer maintains received queue and a sensed queue. On receiving a packet a node put the packet in received queue. If sensed queue is not a empty pick a packet from the head of the received queue and also from head of the sensed queue and generate (XOR)
encoded packet. Detail method of encoded packet generation is given in Algorithm-2. However, the received packet is already processed as an encoded packets then it is discarded by the node. If the node is not an encoder node then, it act as a simple relay node and transmit the received packet to the sink. Here the decoding procedure is performed only at the sinks which process all the gathered data in the wireless sensor network. The lost packets require more energy consumption for the retransmission, so it needs a sophisticated routing protocol.

ALGORITHM 2: XorEncode (): Encoding algorithm

Ensure: Generation of Encoded packet CN
1. If SensQueue () is not empty then continue;
2. Pick a packet Pi from head of the RecvQueue (;)
3. Pick a packet Pj from head of the SensQueue (;)
4. CN = Pi ⊕ Pj;
5. Else
6. Pick next packet Pi+1 from the RecvQueue ();
7. CN = Pi ⊕ Pi+1;
8. Endif;
9. returnCN

Hence multi path kinds of routing technique are used for better reliability with less latency of packet delivery. By using multipath forwarding routing multiple reception of data flow occur . In such a scenario, encoding based approach reduces the traffic inside the bottle neck zone and help in restricting further redundant transmissions. The network coding technique improves the capacity of information with better utilization of bandwidth. The duty cycle and encoding technique can be merged to utilize the network resources efficiently.

IV. PERFORMANCE ANALYSIS AND DISCUSSIONS.

If some of the links fail near the Sink, then the entire energy consumption which is required to relay the packet up-to the bottleneck zone is lost. Different kind of ACK mechanisms is required for the retransmission of lost packets. This will cause further delay to the delivery of the lost data packets and it needs sophisticated routing protocols. Therefore, multipath kind of routing strategy gains its importance in WSN for better reliability with less latency of packet delivery. However, the numbers of paths need to be restricted to control/reduce the redundant data flow. In such a scenario, the proposed encoding based approach reduces traffic inside the bottleneck zone and provides reliability against data loss due to link failure near the Sink. The performance metrics other than the energy efficiency are packet delivery ratio (PDR) and packet latency (PL) [8][9].

The selection of network coder nodes in the coding layer is done by the sink by sending control messages. The improvement of lifetime is due to the introduction of encoding nodes near the sink. A simple MAC protocol is used in which a sensor node waits for a random duration of time before trying to transmit a packet. The nodes keep trying until the transmission is performed. The sensed packet from outside of the bottleneck zone have been created to the sink using flooding protocol in which data packets travel through multiple paths.

Figure 5. Functionalities of the sensor nodes in the bottleneck zone.

Figure 6. Network Lifetime Upper bounds In Duty cycle Based WSN
Figure 6 shows that the network lifetime decreases when the value of m increases. The increase of the value of m suggests that more amount of energy has been consumed in the bottleneck zone for transmissions of the redundant bits. As the duty cycle increases the lifetime decreases in the network. The proposed encoding based communication approach reduces the redundant transmissions of received data at the sink. The sink receives more data with the same number of transmissions in the bottleneck zone by using the proposed network coding based algorithm.

Figure 7 describes that the proposed network coding or encoding based communication approach reduces the redundant transmissions of received data at the sink. The sink receives more data with the same number of transmissions in the bottleneck zone by using the proposed Encoding based algorithm.

Figure 8. Per Node Energy Consumption with Network Coding And Without Network Coding

Figure 8 energy consumption (per node) has been shown for a duty cycle based WSN with network coding and without network coding. The per node energy consumption in case of WSN with duty cycle is more than a WSN with duty cycle and network coding. Energy consumption is reduced by using the proposed network coding based algorithm. The energy consumption in the bottleneck zone has been reduced with 4.28% to improve the lifetime of the overall WSN.

Figure 9 Network Lifetime using The Proposed encoding based Algorithm.

Figure 9 shows that the lifetime with the duty cycle and network coding is more than only using duty cycle. There is an increase 5.14% of network lifetime by using the proposed network coding based communication algorithm.

Figure 10. Energy Consumption reduction using Encoding with single hop and multi hop.

Figure 10 Energy consumption has been shown for a duty cycled based WSN using encoding technique with single hop and multi hop. Energy consumption is reduced by the proposed encoding technique which achieves nearly 4% reduces with single hop and nearly 2% reduces with multihop.
Figure 11. describes the Lifetime analysis with single hop and multi hop. The energy efficiency of WSN increases which in turn improves the network lifetime using the proposed technique. In the single hop scenario, network lifetime is increased with nearly 10% whereas in the multihop scenario, network lifetime in WSN is increased nearly only with 5%. Hence, using an proposed encoding technique with a single hop as coder node provides an better network lifetime than choosing an multihop as coder node.

V. CONCLUSION AND DISCUSSIONS

In a wireless sensor network (WSN), the area around the Sink forms a bottleneck zone where the traffic flow is maximum. Thus, the lifetime of the WSN network is determined by the lifetime of the bottleneck zone. The lifetime upper bounds have been analysed with (i) duty cycle, (ii) Encoding Technique and (iii) combinations of duty cycle and Encoding Technique. It has been observed that there is a reduction in energy consumption in the bottleneck zone with the proposed approach. The simulation results demonstrate that the proposed technique achieves 4.28% of energy saving in single hop and nearly 2% in multihop, and thereby increase of network lifetime in wireless sensor network. Hence, using an proposed encoding technique with a single hop as coder node provides an better network lifetime than choosing a multihop as coder node. Simulation is done by ns-2 simulator. Further, the proposed analysis will be done in omnet++ simulation tools.

VI. REFERENCES


