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Performance Analysis of Energy Adaptive Mechanism for Capacity Maximization in Wireless Sensor Network

Mr.S.Sebastin Suresh[1], Dr. P.R.Jasmine Jeni [2] , Mr.R.Magesh[3]
Asst Prof[1], Professor[2], Asst Prof[3]
PERI Institute of Technology, Anna University, Chennai
Corresponding Author: Mr.S.Sebastin Suresh

Abstract: *Wireless sensor network deals with gathering and send information to observer in network areas. The aim of this paper is to analyse rate and node lifetime using bandwidth. Power and rate mainly depend upon capacity of the sensor networks. An optimization framework is introduced for a multi-hop sensor network topology maximizing the information capacity sent to the sink. Sensor network capacity depends on energy adaptive mechanisms, power-bandwidth control. The capacity optimization problem is defined analytically and practical local schemes are analysed. The performance by varying total bandwidth and the dependence of R_{max} and node lifetime on total bandwidth is observed. Energy dissipation of the sensor network is analysed. Leach algorithm is used for analysing energy dissipation of the sensor network. Simulation result is given for the relation between data collected from sensors and available capacity when relays operating at full power by varying total bandwidth. Simulation result also shows that the performance of rate and node lifetime is based on the capacity and bandwidth.*

Index Terms: *Wireless sensor network, adaptive power control, information capacity.*

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I. Introduction

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. The more modern networks are bi-directional, also enabling control of sensor activity.

According to federal communications commission the current static spectrum allocation has led to the overall low spectrum utilization where up to 70% of the allocation spectrum remains unused called white space at any one time even in a crowded area. Dynamic spectrum allocation has been proposed so that unlicensed spectrum users or secondary users are allowed to use the white space of licensed users or primary user spectrum with low interference with primary users. This function can be realized by implementing cognitive radio in secondary users. Cognitive radio enables cognitive radio sensor network to sense spectrum holes and to dynamically switch its parameter to available white space.

The electromagnetic radio spectrum usage is regulated under strict licensing terms resulting in significant inefficiency in spectrum utilization by the licensed primary users (PU) [1]. Dynamic and opportunistic spectrum access (OSA) as an efficient utilization mechanism allows the secondary users (SU) uses the best available channel [1], [2]. To this end, cognitive radio (CR) is proposed for effective utilization of unused bands opportunistically [3] making it possible for SUs and PUs operate in the same region by adapting the operating conditions of SUs in a manner not to disturb the normal communication standards of PUs.

II. Related Work

Recently, wireless sensor network (WSN) imposing strict cost limitations on sensors has been introduced to the advantages of using nodes with CR capability, i.e. cognitive radio sensor network (CRSN). It increases the reliability of the channel used under bursty traffic, utilizes WSN in crowded spectrum bands without a license, uses adaptive power and bandwidth allocation resulting in lifetime maximization and makes heterogeneous WSN constructions possible [2].

To the best of our knowledge, there is no IT optimization study about CRSNs although some works to optimize the utilization of only a limited set of network resources. In [6], the number of spectrum handoff is reduced. Spectrum utilization and energy efficiency are improved in a multi-objective optimization with a modified game theory solution. Although spectrum allocation and transmission power are optimized, multi-hop routing, ICs and the fundamental features of CRSN, e.g., fast data aggregation, node failures and bursty data traffic, are not considered. Power consumption is reduced by optimizing modulation constellation size [7], through the minimization of energy per bit over the subcarriers [8] and optimization for application oriented source sensing, e.g., collecting information of temperature, sound, etc., and ambient-oriented channel sensing in [10]. Although lifetime and power consumption are optimized, IT metrics and multi-hop CRSN characteristics are not addressed in these works.

III. Overview Of Existing

Multi-hop relaying in WSNs increases the network lifetime with smaller hop distances and lower transmission power. In this article, multi-hop topology is examined with multiple sensors collecting possibly different kinds of information, and forwarding them to a sink node via relaying sensors currently not collecting data. In Table I, global constants and variables of the network model are explained and in Fig. 1(a) and (b), networking topology and its simplified version are shown.

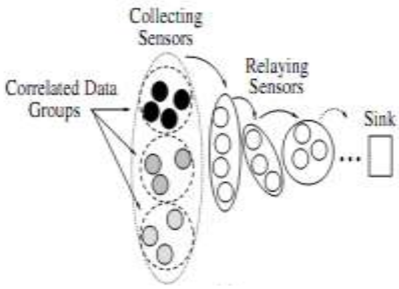

Fig.1 (a). Networking topology of multi-hop relay CRSN

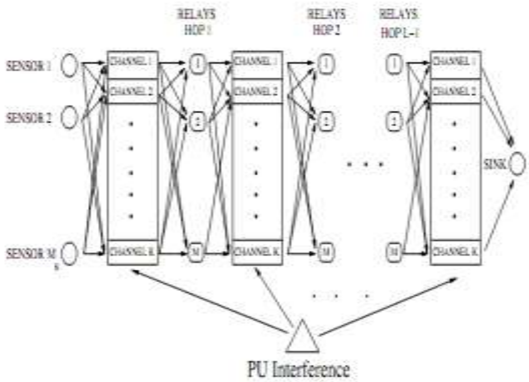

Fig.1.(b) Simplified topology

As shown in Fig. 1(a), the network is assumed to consist of two main groups of sensors, i.e., data collecting sensors and relaying sensors grouped with respect to the distance to the source and sink to simplify routing where the distance between neighboring groups is assumed to be approximately equal leading to symmetric hop levels. A more general network makes the situation complicated to observe the isolated advantages of the discussed optimizations. Besides that, a dense network topology can be assumed, e.g., it can be grouped in such node groups easily by simplifying the routing task.

Table 1 Global constants and definitions for CRSN model

Parameter	Meaning
M_s, M, L	Number of sensors, relays at a hop level and number of hop levels
T_s, t_f	Time slot interval and final duration for sink data aggregation (seconds)
$H(X_{s,j})$	Number of bits sent per time slot for the random variable $X_{s,j}$
$\sigma_S(t^+)$, $\sigma_R(r, t^+)$, $\sigma_D(t^+)$	Noise power spectral density (watts/Hz)
$E_{r,m}$, $E^*_{r,m}(t)$	Initial and remaining energy (joule) at t, r ϵ S_3, m ϵ [1,M]
W_{Tot}	The total available bandwidth
P_{max}	Maximum transmission power

The network has M_s data collecting sensors, L-1 hop count between them and the sink, and at most M relaying sensors at each multi-hop level denoted by r. Sensor data is received and transmitted in time slots of width Ts denoted by t^+ where t is the slot start time. In simulations, sink data is observed until a fixed final time t_f but sensors collect data until t_f for continuous traffic and until several seconds before t_f for bursty traffic.

Relays are assumed to have finite initial energies of $E_{r,m}$ where$E^*_{r,m}$(t) denotes the remaining energy at times. Data collecting sensors are assumed to be capable of continuously collecting and the energy for collecting is not taken into account. Despite the importance of their energy levels, it is assumed that there is a large number of sensors continuously feeding data to multi-hop CRSN and task of data collection of the failed nodes is assigned to nearby sensors. Therefore, it becomes possible to observe the advantages of EA scheme and utilization of IC in multi-hop CRSN for continuous and bursty data traffic while concentrating on data carrying. In a time slot, a transmission power P (Watts) bounded with P_{max} consumes the energy P × T_s. Node failure due to finite relay lifetime is a fundamental WSN constraint and included in optimization architecture.

IV. Proposed Work

The aim of this paper to maintain low energy consumption for data transmission. Energy consumption can be described using low energy adaptive clustering hierarchy protocol. The goal of this protocol is to lower the energy consumption required to create and maintain clusters in order to improve the lifetime of a wireless sensor network. The need of the network protocol is due to the fact that a node in the network is no longer useful when its battery dies. This protocol allows spacing out the lifespan of the nodes and it need minimum work to transmit data.

Nodes are generated randomly. Each node uses a stochastic algorithm at each round to determine whether it will become a cluster head in this round. Nodes that have been cluster heads cannot become cluster head again for P rounds, where P is the desired percentage of cluster heads. Each node has a 1/P probability of becoming a cluster head in each round. At the end of each round, each node that is not a cluster head selects the closest cluster head and joins that cluster. The cluster then creates a schedule for each node in its cluster to transmit its data.

V. Performance Analysis

Capacity is defined as the intrinsic ability of the channel to convey information; it is naturally related to the noise characteristic of the channel. The basic expression, i.e.

C=W log (1+P/ (NW))

Where W is the bandwidth (Hz)
P is the power (Watts)
N is the noise power spectral density (Watts/Hz).

It is desired that P_{max}, W_{Tot} and noise spectral density N_0, it should be possible to transmit the total data received from 3 sensors at time j. information rates of each sensor are assumed to be equal for all sensor and time. P_{max} is chosen such that the maximum signal to noise ratio (SNR) for bandwidth is 10dB.

Capacity is the most important parameter in the sensor network. Rate, node lifetime and energy utilization are depend upon capacity. The rate is increased by varying total bandwidth due to increase the capacity of the node. The energy efficiency is reflected in node lifetime, i.e., LT, where one node gets out of energy. Node lifetime decreases as total bandwidth is increasing since as total bandwidth is increased, the capacity increases. Energy utilization is defined as the ratio of the consumed energy to the total initial energy. Total bandwidth is increased, energy utilization increases due to the increase in the capacity.

Low energy adaptive clustering hierarchy has mainly two phases. The two phases are set-up phase and steady state. In set-up phase cluster head is chosen. In steady state phase, there are two processes. One is cluster head is maintained and other is data is transmitted between nodes. Cluster heads can be chosen stochastically based algorithm and it's given by

$$\mathrm{T(n)} = \frac{\mathrm{P}}{1 - \mathrm{P} \times (\mathrm{r\ mod P^{-1}})}$$

Where n is a random number between 0 and 1
P is the cluster head probability

If n < T (n), then that node become cluster head. The algorithm is designed so that each node becomes a cluster head at least once.

VI. Simulation Result

In this section, performance vs. the total bandwidth is analyzed. Here the ratio of capacity and data rate is compared by varying the total bandwidth. Capacity is determined using the formula given in the performance analysis. Performance of rate and node lifetime is also analyzed. The data rate is calculated for different sensor. By varying bandwidth at the same time, data rate is calculated. Rate is depending upon on the power and bandwidth. Node lifetime of the sensor is determined by using rate and time of the sensor. Node lifetime is depend upon on the bandwidth and time.

Table 2 Global values

Parameter	Value
M_s, M, L	3, 3, 1
$H(X_{s,j})$	11895 bits, 2200 Hz
$\sigma_S(t^+)$, $\sigma_R(r, t^+)$, $\sigma_D(t^+)$	10^{-12} (Watts/Hz)
W_{Tot}	9, 18, 27, 36, 45, 54 KHz
T_s, t_f	1,70 (sec)
P_{max}	3 x 10^{-8} Watts

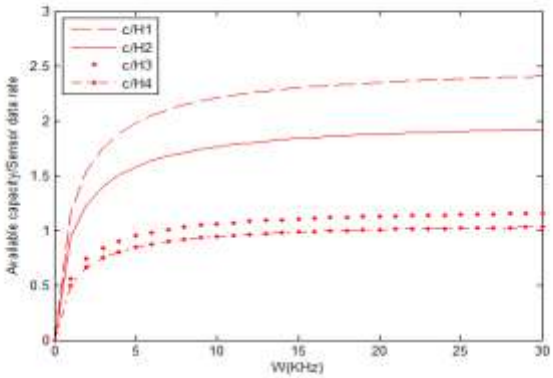

Fig.2. Ratio of available capacity for relays to the data collected from 3 sensors at time j=1 with full operating power

H1 is equal to sensor1 at a time. The ratio of capacity and data rate is high and is approximately equal to 2.4 by increasing the total bandwidth. By varying the total bandwidth, the ratio of capacity and data rate is increased exponentially. H2 is equal to sensor1 and sensor2 at a time. When compared to sensor1 the ratio of capacity and data rate is low and is approximately equal to 1.9. H3 is equal to sensor2 and sensor3 at a time. When compared to sensor1 and senor2 the ratio of capacity and data rate is low and is approximately equal to 1.2. H4 is equal to sensor1, sensor2 and sensor3 at a time. When compared to sensor2 and sensor3 the ratio of capacity and data rate is low and is approximately equal to 1.1.

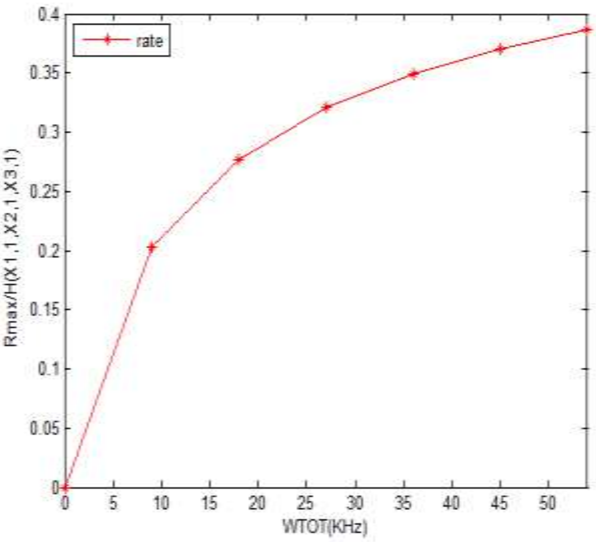

Fig.3. Performance of rate vs total bandwidth

Rmax is observed in Fig.3. The increase in Rmax with WTot is due to the increasing capacity for nodes as shown in Fig. 3. On the other hand, the saturation observed for Rmax upon an increase in WTot resembles the capacity vs. bandwidth for a single link similar to Fig. 2 and it is concluded that Rmax has roughly logarithmic bandwidth dependence like the single channel capacity expression.

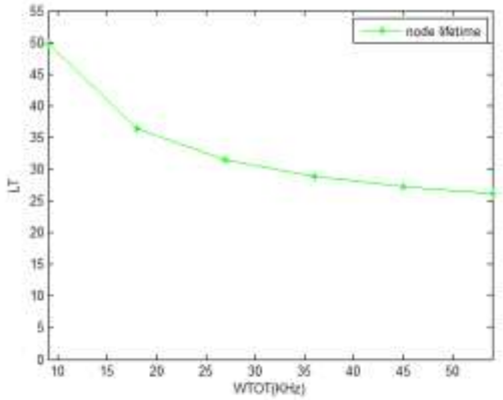

Fig.4. Performance of node lifetime vs total bandwidth

LT decreases and saturates as W_{Tot} is increased since as WTot is increased, the capacity increases and the probability to send data is increased bringing the node depletion. LT performance firstly decreases with increase in W_{Tot} since as the available bandwidth becomes larger; the nodes reach the capability to send data and to consume energy. After a higher level of increase in W_{Tot}, the nodes transmit data more probably and the expected difference due to decrease in the consumed power is not observed in saturated behavior because of the combined effect of fast depletion of nodes and the small initial node energies letting transmission of only a couple of packets preventing to observe the effect of the decrease in the power consumption.

VII. Conclusion

Simulation result is given to the relation between data collected from sensors and available capacity when relays operating at full power by varying total bandwidth. Simulation result is given for the various performances such as rate and node lifetime. The capacity optimization problem will be defined analytically and practical local schemes will be analyzed. Rate and node lifetime are important parameter in the sensor network. Rate and node lifetime are depend upon capacity and bandwidth. When bandwidth is increased capacity and rate is increased and node lifetime is decreased due consumed energy.

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