Receiver Sensitivity in Opportunistic Cooperative Internet of Things (IoT)

(Invited Paper)

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Abstract. In Cooperative communication, a source message is relayed through a locally connected network by means of cooperating network nodes. Recently, the cross layer cooperative schemes have been shown to offer multiple advantages over the single layer approaches. In distributed cooperation schemes, the cooperating nodes make transmission decisions based on the quality of the received signal, which is the only parameter available locally. Receiver sensitivity is the most important parameter of the physical layer and has a direct impact on the MAC layer. This paper proposes a novel cooperative approach for analysis of receiver sensitivity.

Keywords: Cooperative communication, receiver sensitivity, distributed cooperation.

1 Introduction

For monitoring and control of an area with negligible human involvement, wireless sensor network (WSN) is proving to be a hopeful policy. Due to inventions in the micro-electronic circuits, wireless communications and operating systems, WSNs have become a feasible platform which is being used in many applications. The coverage area of a WSN is the placement of sensor nodes in a service area in such a way that the complete service area gets covered [1]. The sensor devices can be placed in the service area either in a fixed or mobile fashion. When we employ random sensor placement, the service area should be well covered or monitored by the sensor devices. Thus, the coverage has been formulated in various ways. Paper [2] defines sensor coverage metric as a surveillance, which can be used as a measurement of the quality of service (QoS) provided by a certain sensor network.

Dense deployment of disposable and low-cost sensor nodes makes the WSN concept beneficial for battlefields. The cooperative communication mechanism is more applicable to AdHoc wireless and WSNs as compared to the cellular networks. Here, each node acts as both a user (source) as well as a relay. In cooperative resource allocation, each node

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transmits for multiple nodes. Effective QoS of the individual network nodes can be improved through cooperation. With cooperative communication, the transmission diversity is achieved by enabling a single antenna device from multi-user scenario to share their antennas and generate a virtual multiple antenna transmitter [3]. Three cooperative mechanisms are possible:

1. Detect (Decode) and Forward: - each node transmits its own bits plus its partner's bit with spreading codes. CDMA implementation is utilized here.
2. Amplify and Forward: - firstly the noisy signal received from the neighboring node is amplified and then retransmitted. At high SNR values, for less number of nodes, it achieves almost full diversity.
3. Coded cooperation: - the information received by the node is re-encoded and then retransmitted. It is inherently integrated into channel coding.

In cooperative communication, the information overheard by neighboring nodes is intelligently used to provide reliable communication between a source and the destination called a sink. In cooperative wireless communication (CWC), several nodes work together to form a virtual array. The overheard information by each neighboring node or relay is transmitted towards the sink concurrently. The cooperation from the wireless sensor nodes that otherwise do not directly contribute in the transmission is intelligently utilized in CWC. The sink node or destination receives numerous editions of the message from the source, and relay(s) and it estimates these inputs to obtain the transmitted data reliably with higher data rates [4].

Opportunistic Large Array (OLA) is a cluster of network nodes which use an active scattering mechanism in response to the signal of the source called leader. The intermediate nodes opportunistically relay the messages from the leader to the sink. The advantage of the OLA is that due to signal enhancement, the SNR of cooperative transmission (SNRCT) is much higher than the SNR of a point to point communication (SNRP2P.). OLAs are considerably flexible and scalable in nature. For cooperative transmission, OLA selects the nodes which have the received signal SNR above some threshold value and the resonance generated by relay nodes carries the actual messages to the desired sinks without causing interference. For the elimination of the routing and multiple access overheads, OLA is a competent physical layer broadcasting algorithm. Multiple clusters of ad hoc wireless nodes can form a multi-OLA system, constructing a multiple access system with the cluster of nodes acting as a team through cooperative transmission rather than transmitting independent data from each node. OLA utilizes the cooperative transmission of the AdHoc network nodes to reach back to a far distant node or sink. Applications of OLA can be: Joint control systems and secure military scenarios where delay cannot be tolerated. OLA is a cooperative mechanism which is simple and scalable [5].

For mobile users, the restrictions in the data rate and QoS are due to variations in the signal attenuation, so some kind of signal multiplicity is very much essential. Various authors have proposed a new form of spatial diversity for the cooperative communication. The results reveal that although the communication channel is noisy, cooperation leads to an increase of capacity of the individual user as well as the overall communication system. Also the user's data rates are less prone to channel variations. Some of the important types of diversity are spatial diversity, temporal diversity and frequency diversity. Higher data rates at reduced transmit power can be converted to an increase in cell coverage [6].

2 Proposed Cooperative IoT Model

The strength of the cooperative OLA approach is that it does not require GPS equipment for identification of the location of the network node entities. The energy savings achieved in WSNs are the result of cross-layer interactive cooperative communication. Routing functions are partially executed in the physical layer as shown in Fig. 1. The diversity provided by MIMO space-time codes can improve performance at the MAC, network and transport layers. Physical layer parameters such as receiver sensitivity significantly affect the MAC protocol. Choice of the medium access scheme is the important aspect of WSNs [7].

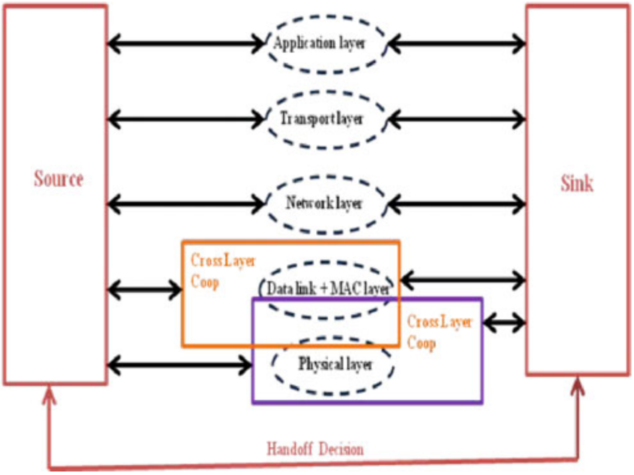

Fig. 1. Cooperative Cross layered Communication

In order to maximize the information transfer among network nodes, the optimal receiver sensitivity is the prime requirement. The noise floor of a receiver determines its sensitivity to low-level signals and its capability of detecting and demodulating those signals. Cooperation allows independently faded radios to collectively achieve robustness to severe fades while keeping individual sensitivity levels close to the nominal path loss. Furthermore, a small number of radios (10-20) are enough to achieve practical sensitivity levels [8]. The proposed cooperative IoT model is depicted in Fig. 2. The nodes which are participating in perticular communication are shown with solid fill.

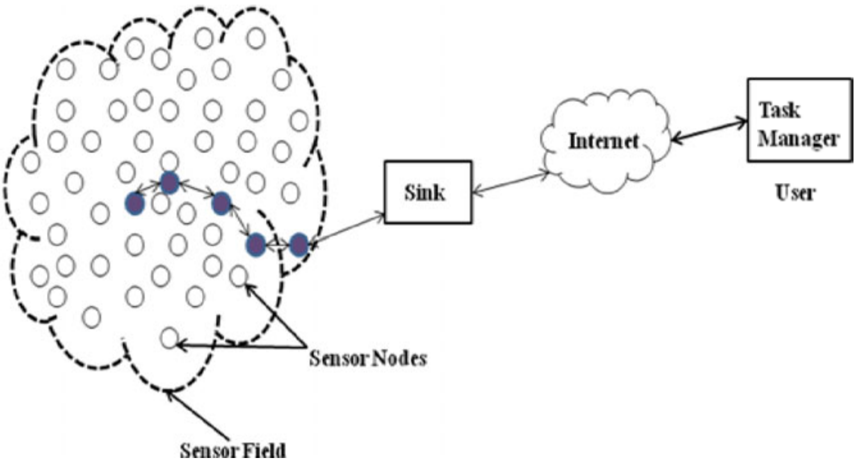

Fig. 2. Proposed cooperative IoT model

3 Analytical System Model

The Decode and Forward mechanism is taken into account for the analytical system model. The wireless sensor nodes with density ρ are uniformly and randomly distributed. The proposed analytical system model is shown in Fig. 3. Radius R_T is the total radius and r is the radius till perticular network node.

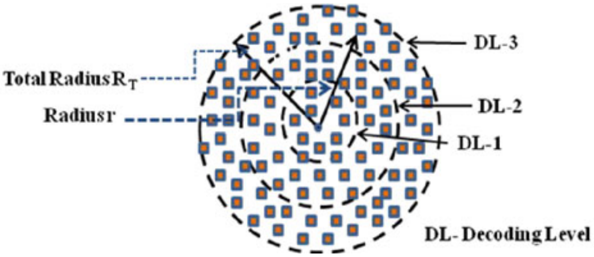

Fig. 3. Proposed Model for Numerical Analysis

Theorem: If $\mu \triangleq e^{(\lambda/\pi\rho P_r)}$ [8] and $\mu > 2$,

Then $$r_k = \sqrt{\frac{P_S(\mu-1)}{\lambda(\mu-2)}}\left(1-\frac{1}{(\mu-1)^k}\right) \quad (1)$$

where $\lambda = decoding\ threshold$
P_S= source power
Pr = relay node power

and $$\lim_{k\to\infty} r_k = r_\infty = \sqrt{\frac{P_S(\mu-1)}{\lambda(\mu-2)}} \quad (2)$$

For ($\mu \leq 2$), the broadcast reaches to the whole network i.e. $lim_{k\to\infty} r_k = \infty$.
For ($\mu > 2$), the total area reached by the broadcast is limited i.e. $r_k < R_T$.

Instead of infinite radius, we are considering some practical scenarios where the radius is limited. Wireless LAN, Bluetooth, etc. are some of the examples for which we can apply limited radius concept.

Table 1. Protocol comparison with different parameters

Protocol/ Parameter	IEEE Spec	Freq. Band	Max Signal Rate	Nominal Range
Bluetooth	802.15.1	2.4 GHz	1 Mbps	10m
UWB	802.15.3a	3.1-10.6 GHz	110 Mbps	10m
Zigbee	802.15.4	868/915 MHz, 2.4 GHz	250 Kbps	10-100m
Wi-Fi	802.11 a/b/g	2.4 GHz, 5GHz	54 Mbps	100m

$$\frac{N_{max}}{\pi R_T^2} \geq \frac{\lambda}{\pi(ln2)P_r} \tag{3}$$

Since we have assumed the noise variance to be unity, the received power becomes received signal to noise ratio (SNR).

$$\text{SNR= Prx} = \frac{\overline{P_r}}{d^2}$$

$$= \frac{\rho Pr}{d^2} \tag{4}$$

The fraction of energy saving is derived based on how many active nodes are utilized for particular cooperative transmission out of total available network nodes in the OLA structure.

$$\text{FES} = 1 - \frac{\substack{number\ of\ active\ radio\ nodes\ utilized \\ for\ cooperative\ transmission}}{\substack{Total\ number\ of\ nodes \\ in\ the\ OLA\ network}} \tag{5}$$

The receiver sensitivity is given by,

$$S_R = K\ (Ta+Trx)\ B\ (SNR) \tag{6}$$

where S_R = receiver sensitivity
K= Boltzman's constant
Ta = equivalent noise temperature in [k] of the source e.g. antenna at the input of the receiver
Trx = equivalent noise temperature in [k] of the receiver referred to the input of the receiver
B = bandwidth
SNR = required SNR at the output

4 Simulation Results

The sensor coverage metric surveillance is used as a measurement of the QoS provided by a certain sensor network [2]. From the plot of Fig. 4, it is observed that for high QoS values, the network node requirement is high. But for low threshold values like Lambda=0.4, the maximum number of node requirement is reduced to 600 for the range of 40 meters.

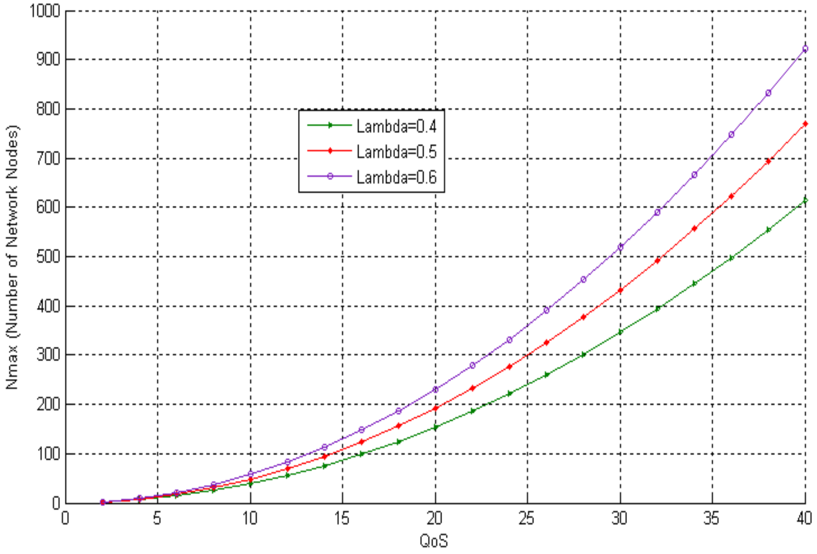

Fig. 4. Nmax versus QoS

As seen from the plot of Fig. 5, for moderate QoS values, considerable energy savings are observed. For decoding threshold Lambda=1.5, the energy savings of 75% is observed for the range of 40 meters. Fig. 6 indicates that for high radius values, the sensitivity is considerably decreased. It indicates better sensitivity of the receiver for distant nodes. Lower power for a given SNR means better sensitivity. Radio devices that fail in unknown ways or may be malicious, introduce a bound on achievable sensitivity reductions [9]. The energy savings are considered on the basis of minimum number of nodes participating in a particular communication purpose out of the total deployed network nodes. As seen from Fig. 6, for small radius, the sensitivity achieved is around -90 dBm, but for the higher values of radius, sensitivity reaches up to -62dBm.

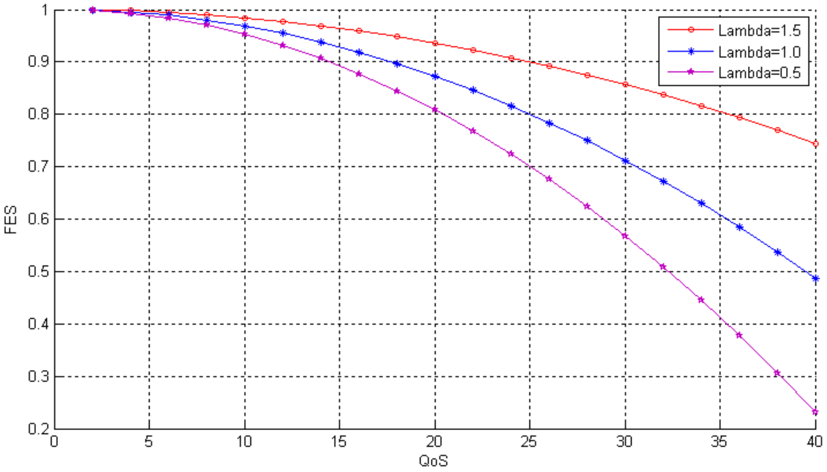

Fig. 5. FES versus QoS

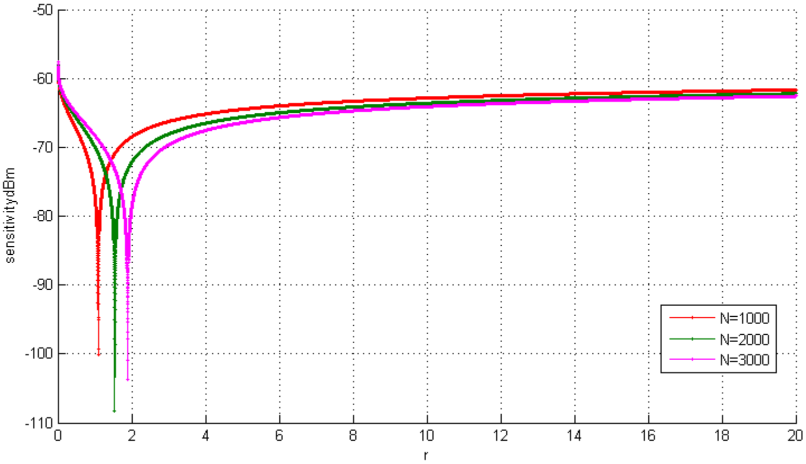

Fig. 6. Sensitivity versus radius

5 Conclusions

In this paper, the cooperative behavior of WSNs is analyzed. The observed high QoS values indicate that our proposed cooperative IoT model is highly reliable. For decoding threshold values of Lambda=1.5, the fraction of energy savings obtained is almost 75%. Since receive sensitivity indicates how faint an input signal can be successfully received by the receiver, the lower the power level, the better is the receiver. Better sensitivity figures are obtained for radius of up to 20 meters. For e.g., sensitivity achieved for 10 meters radius it is around -65dBm. In future works, these results will be extended for the nodes which are malicious or which fail in unknown ways. This work will be extended for security aspects of cooperative IoT systems.

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