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USING LTE TECHNOLOGY IN WIRELESS SENSOR NETWORKS

1. 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 co-operatively pass their data through the network to a main location. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance. WSN is an active research area, and a lot of work is put into techniques to improve them. Wireless cellular network standards have evolved into the 3-rd Generation Partnership Project (3GPP), Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX) systems. In this work investigate the scheduling aspect of using 3GPP (LTE) as a radio transport in WSN applications. This would allow more commodity hardware to be used in the sensor nodes, while also letting WSN designers take advantage of the centralized cellular network model and existing infrastructure. WSNs usually considers a mostly uplink bound network pattern. The archetypical WSN contains sensor nodes which send either continuous or periodic data updates to some centralized aggregation point. In the LTE scheduling request procedure allowed to decrease intensity nodes to use Random Access channel (RACH) exclusively, foregoing their resources in the regular scheduling channel. Aim for this paper is considering ability of increasing the WSN performance by using LTE technology with MIMO systems.

2. The WSN and worldwide cellular Network

One crucial difference between LTE and a traditional WSN is that WSNs are usually envisioned as mesh-type networks, where nodes communicate directly with each other but destination nodes may be out of direct range of transmitters. LTE on the other hand is a centralized star-topology setup, where each node only ever communicates with eNodeB. This can be a disadvantage, for example, the average distance to eNodeB is longer than the average distance to a neighbor, that's mean requires a longer transmission distances which requires more energy. Therefore such a case we suggest using methods of self-organization in sensory systems [1] by using LTE.

On the other hand, the direct connection to eNodeB does away with the need for relay nodes, which evens out the battery life of nodes in the network through the removal of specific roles that would drain some of the nodes faster than others. Additionally, LTE would set IP addresses to nodes and therefore allow WSNs to span multiple cells smoothly. Such a layout allows a single WSN to span a large area, as in the mesh case, having to contend with regional energy depletion fragmenting the network.

Due to the low-traffic nature of a typical WSN and the resource allocation in LTE, it is immediately apparent that the main bottleneck would be control traffic and not data bandwidth. WSN nodes arranged around an event source, it's shown in Figure 1.

To make LTE more suitable for WSN to allow sensor nodes to use random access exclusively, without being scheduled in Physical Uplink Control Channel (PUCCH). LTE currently does not allow such a connection pattern. This would be beneficial in the case where sensor nodes have a low transmission frequency and therefore would waste a lot of resources in PUCCH. In this work proposed to also use RACH instead of PUCCH to send requests for uplink data transmission.

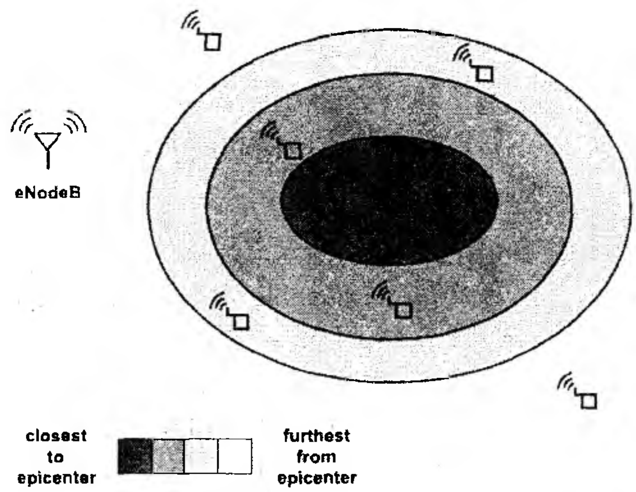

Figure 1. LTE-WSN around an event source

3. LTE-WSN Model

RACH in LTE is a channel used to initiate a random access procedure. At closer inspection one can find modeling of RACH similar to that of multi-channel slotted ALOHA, where preambles of RACH, which divide transmissions orthogonally, can be seen as a number of independent S-ALOHA channels [2]. A number of modifications were made to suit the model to RACH of LTE. One of the major changes is the implementation of collision resolution.

The model describes a number of participating nodes N in the network. At the beginning of each RACH opportunity, each node starts in one of two modes, I-mode (Idle) where nodes transmit a new message with the probability that a node in I-mode transmits (p_N), or B-mode (Backlogged) where nodes retransmit old message with the probability that a node in B-mode retransmits (p_R).

All transmitting nodes from I-mode and B-mode each choose one of K available preambles. Some number of nodes will collide when it's choosing the same preamble as another node, and if collision resolution on eNodeB is disabled, return to B-mode. In case of enabled collision resolution, one node for each collided preamble will be successfully acquired by eNodeB together with those nodes which selected unique preamble. This model shown in Figure 2.

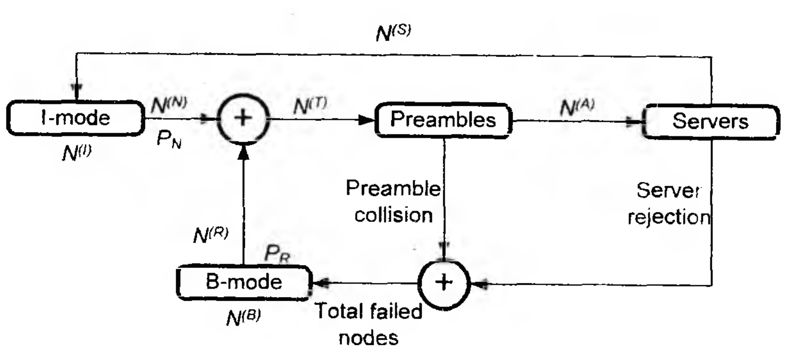

Figure 2. RACH model

From the following properties of the defined model, useful mathematical relations can be derived.

A static number of nodes are in circulation between I- and B-mode. The total number of nodes does not change. Therefore, the following statement holds true

$$N = N_k^{(I)} + N_k^{(B)}, \tag{1}$$

where N the total number of nodes in the network, $N_k^{(I)}$ the number of nodes in I-mode, $N_k^{(B)}$ the number of nodes in B-mode.

Further, due to transmission and retransmission probabilities:

$$N_k^{(N)} = N_k^{(I)} * p_N; \tag{2}$$

$$N_k^{(R)} = N_k^{(B)} * p_R, \tag{3}$$

where $N_k^{(N)}$ the number of nodes performing a new transmission, $N_k^{(R)}$ the number of nodes performing a retransmission.

The total number of transmitting users during RACH opportunity is

$$N_k^{(T)} = N_k^{(N)} + N_k^{(R)}, \tag{4}$$

where $N_k^{(T)}$ the total number of the transmitting nodes.

Due to preamble selection of transmitting nodes and server selection of acquired nodes, the following must hold true

$$N_k^{(S)} \le N_k^{(A)} \le N_k^{(T)}, \tag{5}$$

where $N_k^{(S)}$ the number of node which successfully requested scheduling, $N_k^{(A)}$ the number of acquired nodes.

Due to node's transition from mode to mode properties

$$N_{k+1}^{(B)} = N_k^{(B)} - N_k^{(R)} + failed\_nodes_k, \tag{6}$$

and

$$failed\_nodes_k = N_{k+1}^{(N)} + N_k^{(R)} - N_k^{(S)}. \tag{7}$$

From (6), (7) can get the following equation

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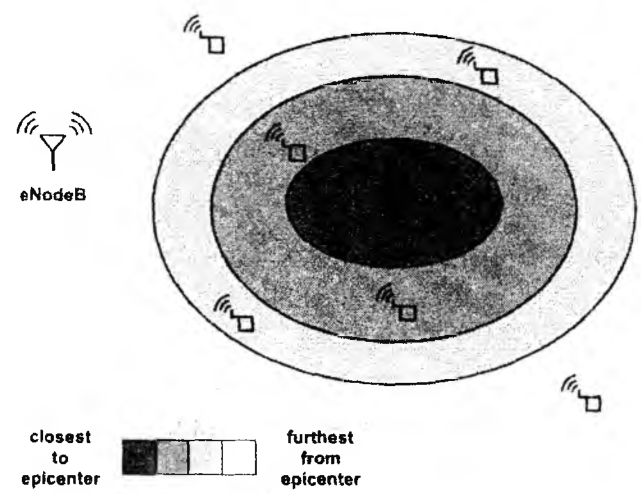
$$N_{k+1}^{(B)} - N_k^{(B)} = N_k^{(N)} - N_k^{(S)}. \tag{8}$$

4. LTE – MIMO systems in eNodeB Wireless Sensor Networks

Multiple Input Multiple Output technology refers to the use of multiple antennas at the transmitter and/ or multiple antennas at the receiver of the system communication. MIMO technology has been shown to improve the communication system performance[3]. The exploitation of MIMO systems in Wireless Sensor Networks where sensor nodes are miniature devices equipped with antennas. On the transmitter side of MIMO system the input data stream is divided into N_T substreams, which are then emitted simultaneously at the same frequency through N_T transmitting antennas its shown in Figure 3. In each of the N_R receiving antennas the signal is under the effect of fading which is added from the mixture of the N_T transmitted signals from the transmitting antennas and also the additive noise [5, 4].



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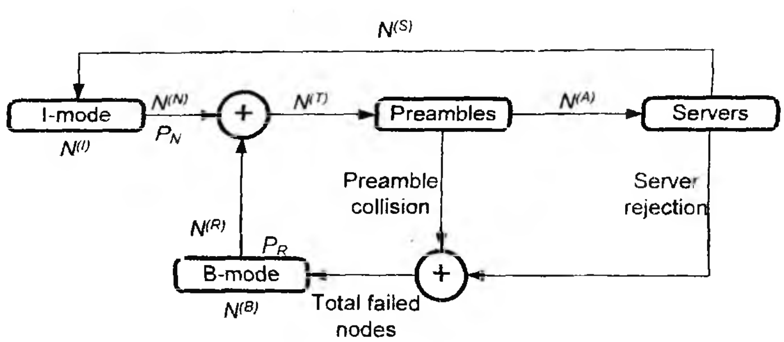

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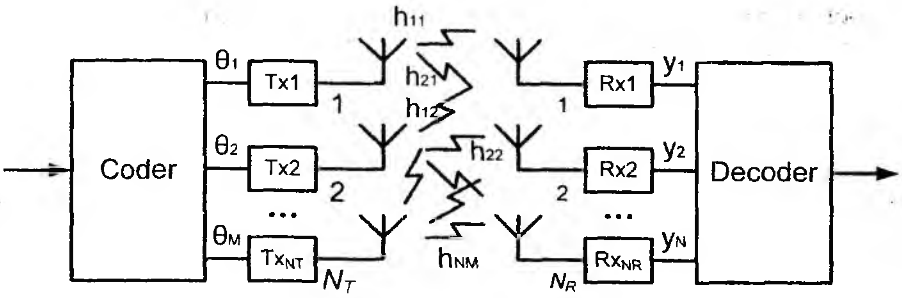

Figure 3. MIMO system model

The complex channel matrix $H = (N_T \times N_R)$is given by

$$H = \begin{bmatrix} h_{11} & \cdots & h_{1N_T} \\ \vdots & \ddots & \vdots \\ h_{N_R 1} & \cdots & h_{N_R N_T} \end{bmatrix}$$

The signals in the receiving channels can be described by a system of linear equations:

$$\begin{cases} y_1 = h_{11}\theta_1 + h_{12}\theta_2 + \ldots + h_{1N_T}\theta_{N_T} + \eta_1; \\ y_2 = h_{21}\theta_1 + h_{22}\theta_2 + \ldots + h_{2N_T}\theta_{N_T} + \eta_2; \\ \\ y_{N_R} = h_{N_R 1}\theta_1 + h_{N2}\theta_2 + \ldots + h_{N_R N_T}\theta_{N_T} + \eta_{N_R}, \end{cases} \tag{9}$$

The system of equations (9) can be rewritten in vector-matrix form

$$Y = H\theta + \eta, \tag{10}$$

where Y – vector of received signals; H – channel matrix of factors; θ – vector transmitted information symbols; η – noise vector [3] [4].

The structure of MIMO system is assumed to be performed by Wireless Sensor Networks (WSNs). The approach of MIMO systems is summarized in Figure 4.

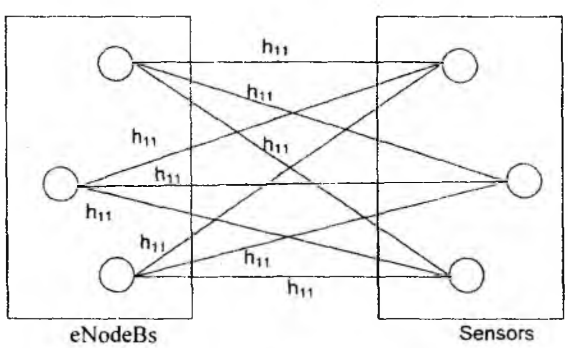

Figure 4. MIMO structure for WSNs

In this work, modeled the energy consumption of simple MIMO systems and compare the value with that of reference SISO systems under the same throughput and bit-error rate (BER) requirement. The energy efficiency is compared over different transmission distances. Suppose that Alamouti diversity codes are used for the MIMO systems.

Energy consumption is the core issue in wireless sensor networks (WSN). To generate a node energy model that can accurately reveal the energy consumption of sensor nodes is an extremely important part of protocol development, system design and performance evaluation in WSNs. The total average power consumption along the signal path can be divided into two main components: the power consumption of all the power amplifiers P_{PA} and the power consumption of all other circuit blocks P_c.The transmitting energy consumption of one bit is defined by Eq (11):

$$E_{bt} = (P_{PA} + P_C)/R_b \, , \tag{11}$$

where E_{bt} is the energy consumption of transmitting one bit when both circuitry and transmission energy consumption are considered, R_b is the bit rate of the system.

The energy consumption of transmitting one bit for long haul MIMO transmission from sensors to eNodeB can be calculated as:

$$E_{bt\_MIMO} = (1+\alpha)\frac{M_t N_0}{P_b^{-1/M_t}} \times \frac{(4\pi d)^2}{G_r G_t \lambda^2} M_l N_f + \frac{P_C}{R_b}, \tag{12}$$

where α is the efficiency of radio frequency power amplifier, M_t number of transmitter antenna, d is the distance, M_l is the link margin compensating the hardware process variations and other additive background noise or interference. N_f is the receiver noise figure, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, λ is the carrier wavelength, P_c power consumption of all circuit blocks.

To utilize Transmit Diversity which called Alamouti Space-Time Code can be applied. It achieves full diversity and works with one receiving antenna. Receive Diversity can be used through more receiving antennas than transmitting antennas and a proper combining algorithm. Switched Combining or Maximum Ration Combining are two examples of algorithms. These work independently of the type of diversity if the channel matrix is known.

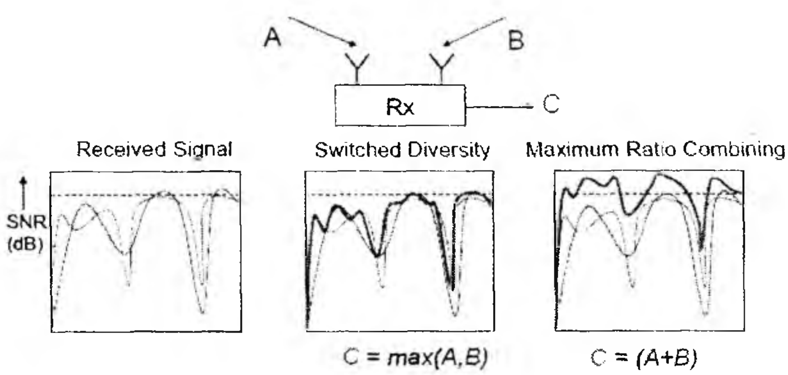

Figure 5. Receiver algorithms for Spatial Diversity, A and B are the same signal

The optimal performance and coverage of a wireless communication system can be reached by Spatial Multiplexing in the near field and Spatial Diversity in the far field. Space-Time Codes additionally improve the performance and make Spatial Diversity useable. The signal copy is not only transmitted from another antenna but also at another time. This delayed transmission is called Delayed Diversity. Space-Time Codes combine spatial and temporal signal copies like in Figure 6. The signals s_1 and s_2 are multiplexed in two data chains. After that a signal replication is added to create the Alamouti Space-Time Block Code [4].

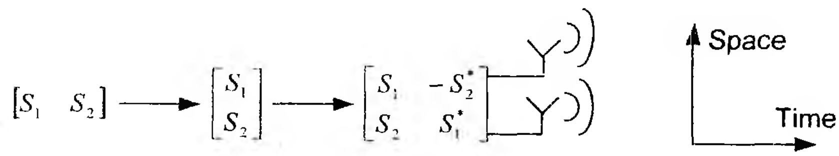

Figure 6. The Alamouti Space-Time Block Code for 2 T_x antennas

The first code is the easiest way to achieve Spatial Diversity and is widely used. The second code is more complex and expensive nowadays. For more than two antennas there are several Pseudo-Alamouti Codes shown in Figure 7.

$$S_{32} = \begin{bmatrix} S_1 & -S_2^* \\ S_2 & S_1^* \\ S_3 & S_4 \end{bmatrix} \quad S_{42} = \begin{bmatrix} S_1 & -S_2^* \\ S_2 & S_1^* \\ S_3 & S_4^* \\ S_4 & S_3^* \end{bmatrix} \quad S_{43} = \begin{bmatrix} S_1 & -S_2^* \\ S_2 & S_1^* \\ S_3 & S_4 \\ S_5 & S_6 \end{bmatrix}$$

Figure 7. Composite Alamouti Code for more than 2 transmits antennas

The index of the Codes above relates firstly to the number of antennas and secondly to the number of spatial data streams. Apart from S_{42} these do no achieve full diversity and four data streams can only be realized by Spatial Multiplexing without any Spatial Diversity.

The developed an optimized Space-Time Block Code to increase the code rate to 3/4. This Quasi-Orthogonal STBC is efficient but permits some Inter-Symbol-Interferences (ISI). Despite this, the bit error rate (BER) is still within the tolerance range. None of these codes are able to achieve full code rate like Alamouti.

Simulation Result

The results of simulation BER with 2 X 2 Alamouti STBC of 1x1 SISO, 1x2 MRC , 2x1 MISO Alamouti and 2x2 MIMO Alamouti, shown in the Figure 8.

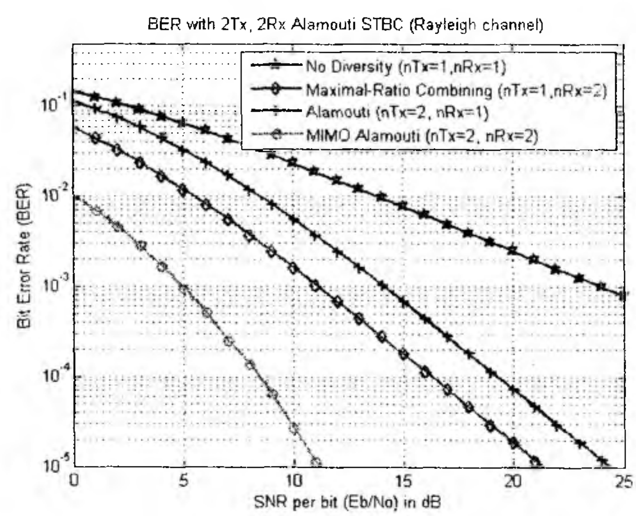

Figure 8. BER with 2 x 2 Alamouti STBC

The energy efficiency in MIMO system for multihop WSN has been explored to minimize the energy consumption and increase the lifetime of sensor nodes and the performance of the system is evaluated. Since 2 x 1 MISO or 2 x 2 MIMO system support higher data rates than SISO in

Rayleigh fading channels, it is possible to have higher constellation sizes for MISO and MIMO systems with certain the BER requirement, its shown in the Figure 9 and Figure 10.

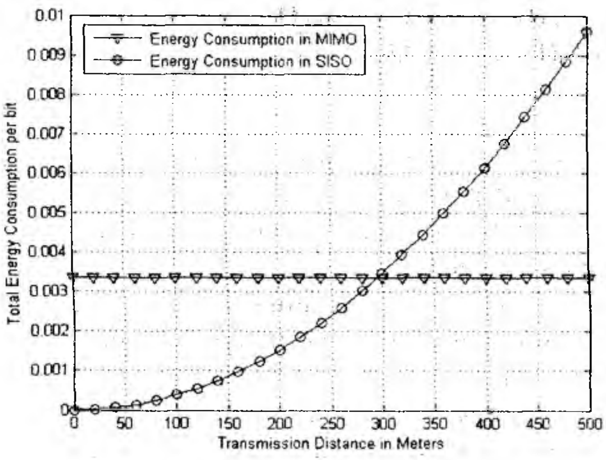

Figure 9. Total energy consumption per bit over d for MIMO and SISO

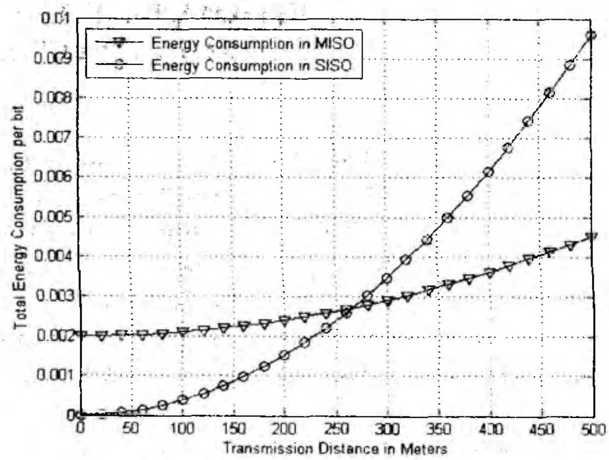

Figure 10. Total energy consumption per bit over d for MISO and SISO

So the simulation results in a Figure 9, 10 shows that the circuit energy consumption prevails the transmission energy when distance is small, and the extra receiver branch in the 2 x 2 MIMO adds more circuit energy consumption than in the 2 x 1 MISO. When the low distance a SISO is more energy efficient is even larger than the MISO case.

Conclusion

1. By using MIMO technology provides higher energy efficiency, energy consumption is reduced to a minimum, which also contributes to the life of the sensor nodes in WSN.

2. By using LTE with MIMO support higher data rates, because it can be used multi-position modulation with higher order constellations.

3. To make LTE more suitable for WSN to allow sensor nodes to use random access exclusively, also must use RACH instead of PUCCH to send requests for uplink data transmission.

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