Abstract

This paper presents the energy optimization of MIMO and Co-operative MIMO technology in wireless sensor network. Here TRAMA is used for energy optimization purpose which provides collision-free transmissions, energy-efficiency, channel utilization, and higher throughput. It saves a significant amount of energy (nodes can switch to sleep mode approximately 87% of the time) depending on the offered load in wireless sensor network. One key limitation is that it has higher delay but guarantees for higher delivery of data and energy-efficiency. The simulation results show that it out-performs CSMA, 802.11, and S-MAC when compared to contention-based protocols.

Introduction

WSN is built of nodes from a few to several hundreds or even thousands of nodes which are connected to one (or sometimes several) nodes capable of sensing, communication and computation. The main function of wireless sensor nodes include ease of installation, self configure, reliability and time constraint communication with the neighbouring nodes. Wireless sensor nodes are deployed in large number to monitor, sense and understand the physical properties of environment around them by measuring the temperature, humidity and relative pressure and transmit the information over radio links. Multihop communication is used in sensor network because transmissions over long distance require more power but sensors have limited power source. The sensed or gathered data is transmitted to the sink node. The nodes in WSN are battery operated and it has limited source of energy. Hence we need to optimize energy so that we can save a lot of energy when there is no communication among nodes. MIMO uses multiple transmitter antennas and receiver antennas to transfer data in which SISO, SIMO, MISO are special cases of MIMO. MIMO supports higher data rate but consumes a significant amount of energy for long range transmissions.Due to its complex circuitry, there is also more energy consumption but circuit energy is dominated by transmission energy. So we need to optimize this transmission energy to save battery life for long time. Here is the diagram of MIMO using multiple transmitter antennas and receiver antennas :

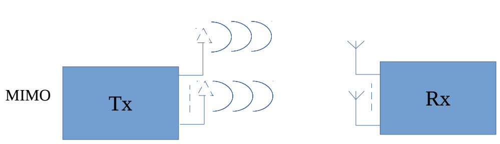

Figure 1 : MIMO

Wireless sensor network has various area of applications . For instance these are widely used in process management, health care monitoring, environmental/earth sensing, industrial monitoring, etc.

This paper is organized as some challenging issues in wireless sensor network. After that MIMO section is presented with system model followed by the techniques used to in optimizing energy consumption of MIMO. In the next section Co-operative MIMO technology is introduced and also shown how they are used in optimizing energy consumption of MIMO by co-operating the other nodes. Then the results section are shown via comparison followed by conclusion section.

Challenges or Issues

Wireless sensor networks have some extreme resource constraints which are energy , bandwidth , buffer size and transmission capacity of sensor nodes. There is a crucial issues of energy consumption in wireless sensor network as in most of the cases batteries of sensor nodes are not rechargeable or replaceable “e.g. sensors in a large forest , sensors in the battle field , etc”. Sensor nodes lifetime depends on their batteries. When power of batteries are dissipated, the nodes are dead which are of no use and leading to elimination of wireless networks. Most energy expensive operations in wireless sensor networks are idle listening (sitting idly and trying to receive when nobody is sending) and data transmission. Collisions of packets , control overhead and overhearing (receiving a packets destined for others) are also major source of energy consumption in wireless sensor networks. Sensors consume more energy in communication than energy consumed in sensing and data processing. Saving and efficient utilization of energy is a big challenge in wireless sensor networks.

Efficient bandwidth utilization is also a significant challenge in wireless sensor networks. The traffics in wireless sensor networks may involve mixture of real time and non real time. In order to response certain important events such as fire outbreak, earthquakes, or enemy movements, sensor nodes become active and the sudden surge of data from hundreds or even thousands of sensor nodes must be delivered to a small number of base stations, which may cause congestion. It is a critical problem to resolve congestion, such that all data sources have equal or weighted access to network bandwidth.

Channels are a scarce resource in wireless sensor network. Wireless channel is less reliable in nature. The transmitted packets can be prevented from reaching to the receiver by some phenomena. One of those challenge is interference. Interference between concurrent transmissions can degrade the performance in wireless sensor networks. This causes transmitters to re-transmit the signal which costs extra time and energy. To handle heterogeneous data from different types of sensor nodes is another challenge in wireless sensor network. For instance some applications using different types of sensor nodes to monitor temperature, pressure, humidity of surrounding environment delivers heterogeneous data to base stations.

MIMO Communication

System Model

We have considered a general communication link connecting two wireless nodes, which can be MIMO, MISO, SIMO, or SISO. Total energy consumption includes all signal processing blocks at the transmitter and the receiver. To avoid from complication we have omitted baseband signal processing blocks (e.g., pulse-shaping, digital modulation, source coding). We have assumed that the system is uncoded hence no error correcting code blocks are included. The signal paths on the transmitter and the receiver sides are shown in following figure.

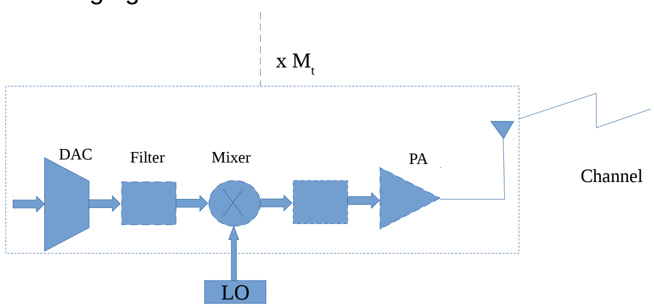

Figure 2 : Transmitter Blocks (Analog)

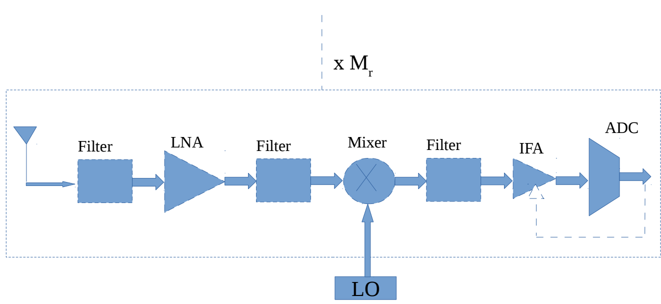

Figure 3 : Receiver Blocks (Analog)

where M_t and M_r are the numbers of transmitters and receivers antennas. In order to estimate total energy consumption we have to consider energy consumption of all circuit blocks and power amplifiers in which power amplifiers are dependent on transmit power P_{tr} which is given as follow-

$$P_{tr} = E_{pb} R_{br} \{(4\pi x)^2 / G_t G_r \lambda^2\} M_l N_f$$

Here E_{pb} is energy per bit at the receiver for a given BER requirement, R_{br} is bit rate, x is transmission distance G_t is transmitter antenna gain, G_r is receiver antenna gain, λ is carrier wavelength, M_l is link margin compensating the hardware process variations, N_f is receiver noise figure (N_r / N_0) with N_0 = single sided thermal noise power spectral density (PSD) at room temperature and N_r = PSD of the total effective noise at the receiver input.

The energy consumption of power amplifiers can be given as-

$$P_{pa} = (1+\alpha)P_{tr}$$

where $\alpha = \xi/\eta$ with η drain efficiency of the RF power amplifier and ξ peak to average ratio.
Now energy consumption of all the circuit blocks is approximately given as-

$$P_{ckt} = M_t (P_{dac} + P_{mixr} + P_{filtr}) + 2P_{syn} + M_r (P_{lna} + P_{mixr} + P_{ifa} + P_{filrr} + P_{adc})$$

where P_{dac} , P_{mixr} , P_{lna} , P_{ifa} , P_{filtr} , P_{filrr} , P_{adc} , P_{syn} are energy consumption values of DAC, mixer, low noise amplifier (LNA), intermediate frequency amplifier (IFA), filters, ADC and frequency synthesizer at transmitter and receiver side as shown in above figure. Now total energy consumption per bit is given as-

$$E_{total} = (P_{pa} + P_{ckt}) / R_{br}$$

Now we have discussed in the next section that includes technique used in optimizing energy consumption, working principles, comparison of the results and then the conclusion part.

Used Energy Optimizing Technique

We have used traffic adaptive medium access (TRAMA) protocol in optimizing energy consumption of MIMO system. TRAMA consists of mainly three components : Neighbor protocol (NP), Schedule exchange protocol (SEP) and Adaptive election algorithm (AEA). For data and signaling transmission TRAMA assumes time-slotted channel : (1) scheduled-access as transmission slots and (2) random-access as signaling slots. It is shown in following figure-

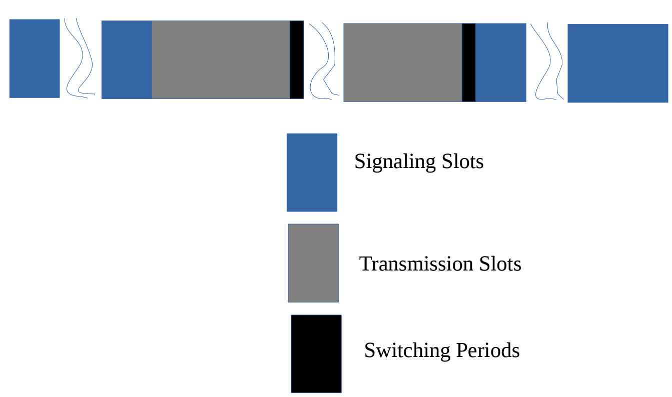

Figure 4 : Time-slot

During random-access period the new nodes can join the network. Its main characteristics is to allow node additions and deletions. In order to send updates to neighboring nodes and receiving updates from them all nodes must be either in transmit state or in receiving state respectively. During random-access period collision may occurs so for consistent neighborhood information its length should be 7*1.44*N (99% guarantee to be delivered). Scheduled-access period is used for schedule propagation and collision free data exchange.

By exchanging small signaling packets NP gather information during random-access period. Signaling packets provide incremental neighborhood updates and connectivity between neighbors. The format of signaling packet is shown here-

Type	Source Address	Dest Address	Del Num	Add Num	Deleted Node	Added Node

Figure 5 : Signal Header

If for a certain period of time a node does not hear a neighbor it times out that neighbor. But updates are re-transmitted such that there is 0.99 probability of success. SEP maintains and establishes traffic-based schedule information by the transmitter and the receiver. Schedule generation algorithm is given as follow :

1. Compute the SCHEDULE INTERVAL
2. Pre-compute the number of slots in the interval [t, t + SCHEDULE INTERVAL] as winning slots
3. Announce the intended receiver for these slots
4. If (not enough packets to transmit)
    Give-up the corresponding slots
    Let other nodes to transmit their data
5. Use last winning slots to broadcast nodes schedule for next interval

Here SCHEDULE INTERVAL represents the number of slots for which the node can announce the schedule to its neighbor and winning slots have highest priority among its two-hop neighbors.

Before the actual transmission a node has to announce its schedule using SEP which announce its schedule using the following schedule-packet format :

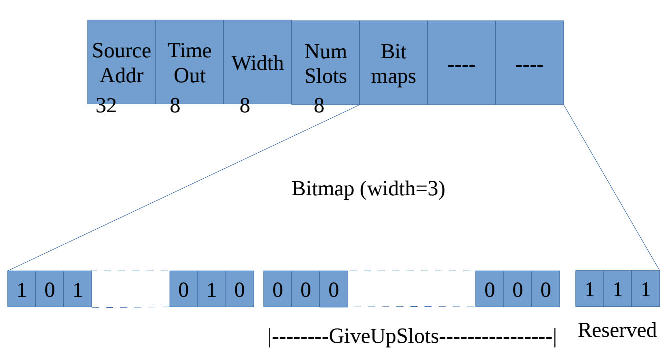

Figure 6 : Schedule-packet format

If we see the packet format there is no receiver address because nodes use bitmap whose length is equal to the number of one-hop neighbors and each bit in bitmap corresponds to a particular receiver ordered by their identities. Total number of receivers that can be supported depends on the size of data slots and the number of slots for which receivers are announced. The advantage of using bitmap is that broadcasting and multicasting can be done easily. To broadcast all bitmap bits are set to 1 (one) and to multicast only those particular bits are set to 1 (one). The bitmap bits are set to 0 (zero) for vacant-slots so that nodes in two-hop neighbors can use these slots. If it happens that after some slot all the winning slots go unused then it is called "ChangeOver slot" and it happens contiguously upto end but before the last winning and also maximizes the length of sleep periods. In packet format source Addr is address of node announcing schedule, time-out is number of slots for which schedule is valid, width is the length of the neighbor bitmap and numSlots is the total number of winning slots. The last winning slot is always reserved for announcing the next schedule.

Every data packet carries a summary of node's schedule which help in minimizing the effect of packet loss in schedule dissemination. The data packet header is shown as follow :

Type	Source Address	Dest Address	TimeOut	NumSlots	Bitmap

Figure 7 : Data Header

The size of bitmap which is equal to NumSlots and indicates that node is transmitting or giving up the slots. To ensure consistency across one-hop neighborhood nodes are not allowed to change the schedule before schedule time-out expires. During the ChangeOver slot all nodes have to listen to synchronize their schedule because unsyncronization may occurs only until the ChangeOver slot.

The nodes can be in any one of states i.e. transmit state, receive state or sleep state. Each node runs AEA to know its state by information of two-hop neighborhood nodes and schedule announced by one-hop neighboring nodes. A node can be in transmit state if : (a) it has data to send, and (b) it has highest priority among its two-hop neighboring nodes.The priority of nodes are calculated using MD5 hash based on concatenation of node x identity and time-slot :

$$\text{priority}(x, t) = \text{MD5}(x \oplus t)$$

If the node is not a transmitter then it will consult schedules sent out by one-hop neighboring nodes to decide its receive state. The nodes can switch to sleep mode if the transmitter has no traffic to them during the current time-slot. The state of the node depends on schedule announced by one-hop neighboring nodes and the Absolute Winner. The absolute winner at any given time-slot t can be defined as : (a) the node x itself, (b) the node y that lies in two-hop neighboring nodes of x in which case the Alternate Winner needs to be accounted for if hidden from node y, or (c) the node z that lies in node x one-hop neighboring nodes. Absolute winner and Alternate winner is shown in following figure :

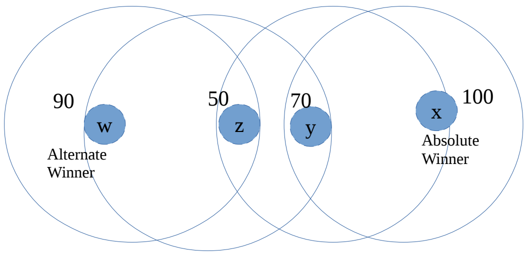

Figure 8 : Inconsistency among nodes due to hidden alternative node from absolute winner

The algorithm details is given as follow :

```
Find abs(x), alt(x), and nt(x)
if (x = abs(x)) then
    if (x.sentSchedule = TRUE) then
        x.state = transmit
        x.receiver = x.reported.rxId
        send the packet and update the sent schedule
        else if (x.giveupSlot = TRUE) then
        call NeedTransmitterHandling
    endif
else if (abs(x) ∈ OHS) then
    if (abs(x).sentSchedule = TRUE && abs(x).giveupSlot = TRUE) then
        call NeedTransmitterHandling
    else if (abs(x).sentSchedule = FALSE || abs(x).announcedReceiver = x) then
        x.state = receive
    else
        x.state = sleep
        Update schedule for abs(x)
    endif
else
    if (alt(x) hidden from abs(x) && alt(x) ∈ OHS) then
        if (alt(x).sentSchedule = TRUE && alt(x).giveupSlot = TRUE) then
            call NeedTransmitterHandling
        else if (alt(x).sentSchedule = FALSE || alt(x).announcedReceiver = x) then
            x.state = receive
        else
            x.state = sleep
            Update schedule for alt(x)
        endif
    else
        call NeedTransmitterHandling
    endif
Function NeedTransmitterHandling
if (nt(x) = x) then
    x.state = transmit
    x.receiver = x.reported.rxId
    send the packet and update the sent schedule
else if (nt(x).sentSchedule = FALSE || nt(x).announcedReceiver = x) then
    x.stae = receive
else
    x.mode = sleep
    Update the schedule for nt(x)
endif
```

There may occur a situation that the selected transmitter has no data to send so the time-slot will go wasted. To use those time-slots TRAMA maintains a set of nodes called one-hop set (OHS) which contains all one-hop neighboring nodes that can possibly use these extra time-slots to send their data and also a set of nodes called data set (DS) which is a subset of one-hop set but contains only those nodes that have data to send. In this situation, data set is checked and node with highest priority is selected as transmitter called as need transmitter. The nodes can switch to sleep mode those are not in the schedule listed the selected transmitter to save energy.

Co-operative MIMO communication

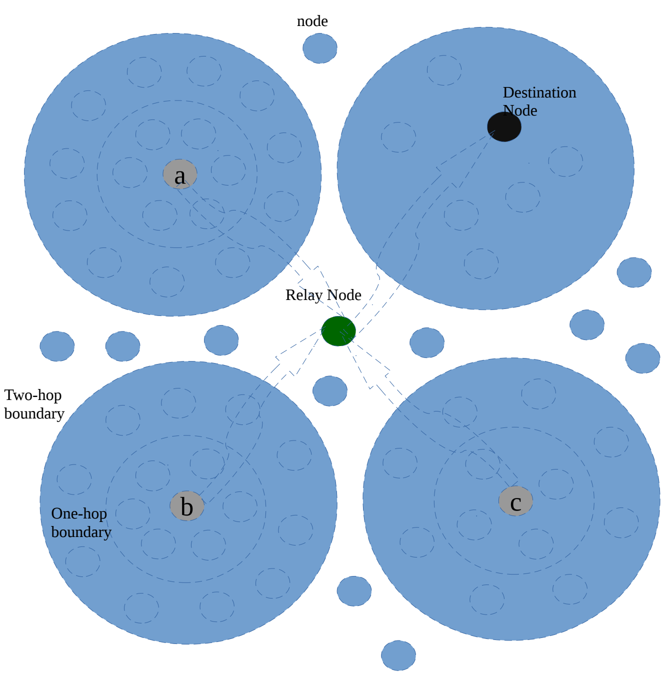

Figure 9 : Co-operative MIMO

In co-operative MIMO the nodes perform co-opration to transmit the data. The nodes that have data to send, first they transmit their data to relay nodes depending upon the position of destination node and then relay node can forward to other releay node and finally to the destination node. Here the transmitter is selected as TRAMA defines which has been discussed already in previous MIMO section. The transmitter nodes send their data by co-operating the other nodes which saves a lot of energy compared to direct transmission of data from source node to destination node. The algorithm is given as following :

Let M_t is the number of transmitters selected to transmit the data, R_n is releay node, and D_n is the destination node.

1. Begin
2. Select all the transmitters M_t using TRAMA
3. PAR for (i=0 ; i<M_t ; i++)
4. M_t.sendData( )
5. R_n.collectData( )
6. Repeat step **7**
7. If(R_n != D_n)
Forward the data to other relay node
8. Stop.

Results

From simulation results the delay performance is compaerd as following :

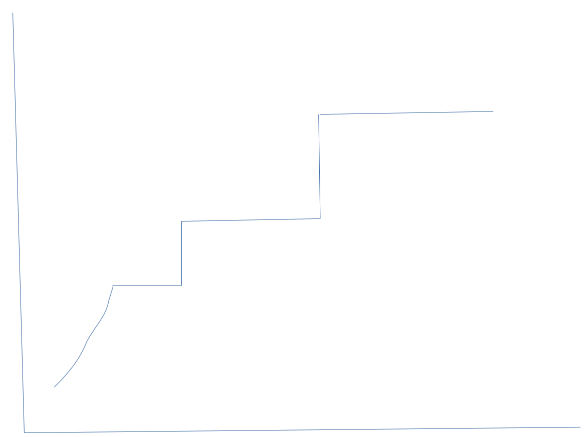

Figure : Delay performance

The energy consumption of MIMO is compared as following :

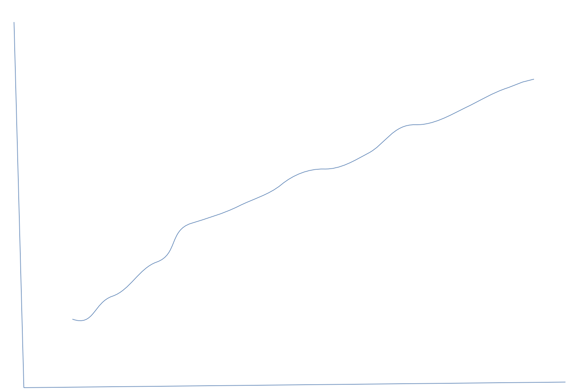

Figure : Energy consumption

It can be seen from above figure that our results is more energy efficient than other.

Conclusion

From simulation results it can be seen that TRAMA out-performs other protocols in terms of energy consumption. It makes all other nodes to switch in sleep mode that are not involving in communication hence saving a lot of energy. It provides collision-free transmission because in its two-hop neighboring nodes there is no other transmitter is sending any data. There is one more important fact i.e. channel utilization when transmitter has no data to send and the current time-slots are used by another nodes to transmit their data.

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