



Energy Optimization of MIMO and Co-operative MIMO in Wireless Sensor Networks

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Abstract—In this paper, traffic information in wireless sensor network is used in optimizing the energy consumption of MIMO systems. Since the nodes in wireless sensor networks are battery operated having limited source of energy. So in order to minimize energy consumption, the best traffic adaptive protocol is used which provides collision-free transmissions and make the other nodes to switch in sleep state that are not involved in transmitting or receiving the data to save a lot of energy (since the nodes can switch to sleep state approximately 87% of the time) depending on the offered load in wireless sensor network. It is not only energy efficient but also guarantees for higher delivery of data and makes better use of channel utilization. In order to optimize energy consumptions for local or long haul transmissions of data in Co-operative MIMO, neighboring nodes are used to form an optimal set or group of nodes which co-operatively transmit their data to relay node or to the destination node based on their position in wireless sensor network. Here data are transmitted to the destination nodes using multiple relay nodes which results a lot of energy saving rather than direct transmissions of data to the destination node. Hence, there is an increase in life-span of nodes in wireless sensor network.

Keywords—Wireless Sensor Network, MIMO, Energy Optimization, Co-operative MIMO, TRAMA.

I. INTRODUCTION

Wireless sensor network 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 wireless sensor network 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 with some challenging issues in wireless sensor network in section II. In section III MIMO communication is presented with system model followed by the techniques used in optimizing energy consumption of MIMO. In the next section IV Co-operative MIMO technology is introduced and also shown how they are used in optimizing energy consumption of MIMO by co-operating with the other nodes followed by section V conclusion part and references.

II. CHALLENGES

Wireless sensor networks have some extreme resource constraints which are energy, bandwidth, and 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 is 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 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 challenges 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.

III. MIMO COMMUNICATION

A. 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.

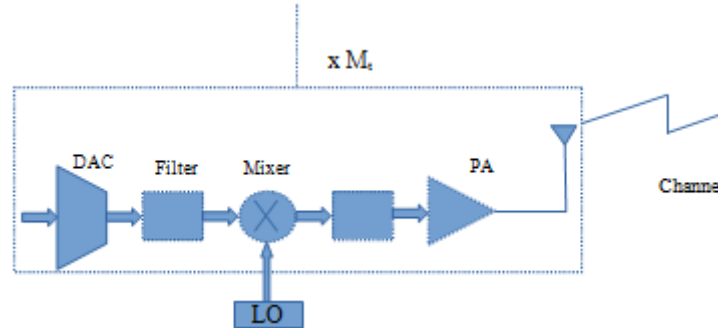


Figure 2 : Transmitter Blocks (Analog)

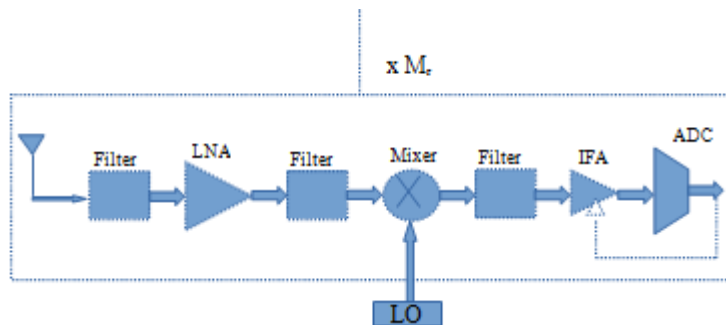


Figure 3: Receiver Blocks (Analog)

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-

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

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_1 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-

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

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-

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

Total energy consumption includes both the circuit energy and the transmission energy. So traffic-based information in wireless sensor network is used in optimizing the energy consumption which is discussed in the next part.

B. Energy Optimizing Technique

Traffic adaptive medium access (TRAMA) protocol is used in optimizing energy consumption of MIMO system. It uses traffic information of nodes and perform required action that other nodes have to take means state of nodes. 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-

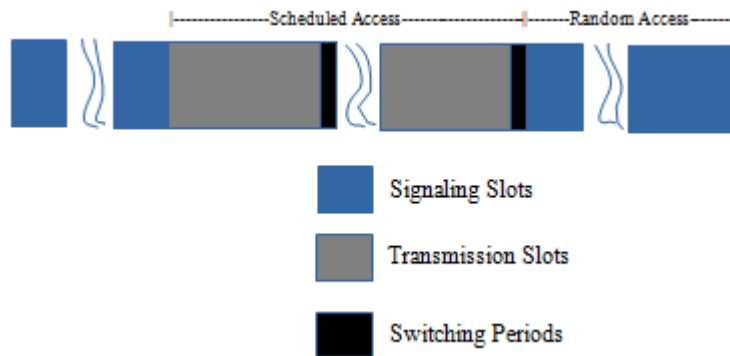


Figure 4 : Time-slot

During random-access period the new nodes can join the network. Their main characteristic 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). This is verified from experts but it may be variable. 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	Destination Address	Delete Num	Add Num	Deleted NodeID's	Added NodeID's
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Figure 5: Signaling Packet

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 $[t, t + \text{SCHEDULE INTERVAL}]$ 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 :

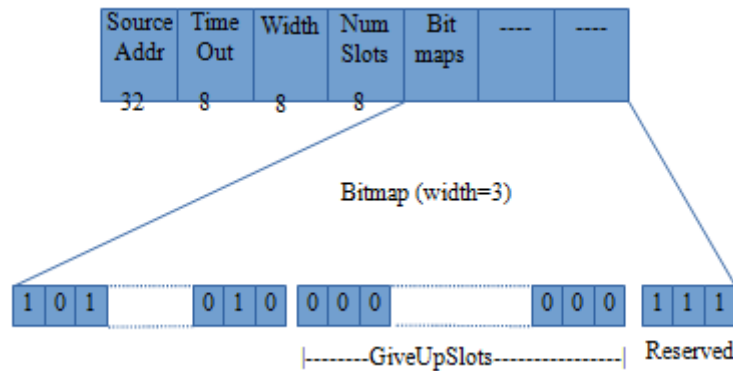


Figure 6: Schedule-packet format

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 to transmit their data. 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 slot which is reserved for broadcasting its schedule, and it 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
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Figure 7 : Data Packet

The size of bitmap 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 non synchronization may occur 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 t :

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

If the node is not a transmitter then it will consult schedules sent out by one-hop neighboring nodes to decide its receive state or sleep state. The nodes can switch to sleep mode if the transmitter has no traffic forwarded 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 $\text{abs}(x)$. 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 $\text{alt}(x)$ 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 :

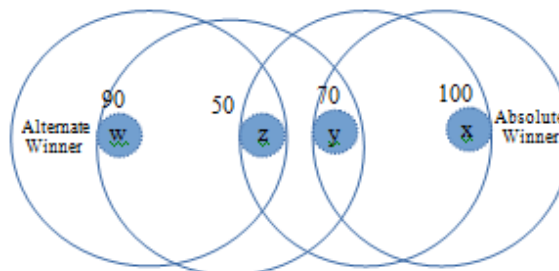


Figure 8 : Inconsistency among nodes

Alternate winner is that node which has highest priority among its two-hop neighboring nodes and it is hidden from absolute winner means they are three hop away from each other that's why Inconsistency occur. There may occur a situation that the selected transmitter has no data to transmit 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 transmit their data and also a set of nodes called data set (DS) which is a subset of one-hop set (OHS) but it contains only those nodes that have data to send. When transmitter has no data to send, data set is checked and the node with the highest priority is selected as the transmitter called need transmitter $nt(x)$. TRAMA selects nodes in such a way that there is no intended receiver which is idle and no receiver suffers from collisions.

The following algorithm describes how it selects the transmitters, receivers, stand-by nodes and also handles inconsistency problems among nodes. The algorithm detail is described as follow:

```
1. Find  $abs(x)$ ,  $alt(x)$ , and  $nt(x)$ 
2. if ( $x = abs(x)$ ) then
3.     if ( $x.sentSchedule = TRUE$ ) then
4.          $x.state = transmit$ 
5.          $x.receiver = x.reported.rxId$ 
6.         send the packet and update the sent schedule
7.     else if ( $x.giveupSlot = TRUE$ ) then
8.         call NeedTransmitterHandling
9.     endif
10. else if ( $abs(x) \in OHS$ ) then
11.     if ( $abs(x).sentSchedule = TRUE \ \&\& \ abs(x).giveupSlot = TRUE$ ) then
12.         call NeedTransmitterHandling
13.     else if ( $abs(x).sentSchedule = FALSE \ || \ abs(x).announcedReceiver = x$ ) then
14.          $x.state = receive$ 
15.     else
16.          $x.state = sleep$ 
17.         Update schedule for  $abs(x)$ 
18.     endif
19. else
20.     if ( $alt(x)$  hidden from  $abs(x)$  &&  $alt(x) \in OHS$ ) then
21.         if ( $alt(x).sentSchedule = TRUE \ \&\& \ alt(x).giveupSlot = TRUE$ ) then
22.             call NeedTransmitterHandling
23.         else if ( $alt(x).sentSchedule = FALSE \ || \ alt(x).announcedReceiver = x$ ) then
24.              $x.state = receive$ 
25.         else
26.              $x.state = sleep$ 
27.             Update schedule for  $alt(x)$ 
28.         endif
29.     else
30.         call NeedTransmitterHandling
31.     endif
32. Function NeedTransmitterHandling
33. if ( $nt(x) = x$ ) then
34.      $x.state = transmit$ 
35.      $x.receiver = x.reported.rxId$ 
36.     send the packet and update the sent schedule
37. else if ( $nt(x).sentSchedule = FALSE \ || \ nt(x).announcedReceiver = x$ ) then
38.      $x.stae = receive$ 
39. else
40.      $x.mode = sleep$ 
41.     Update the schedule for  $nt(x)$ 
42. endif
```

In step 1-9, the node is selected as absolute winner among its two-hop neighborhood that have data to send. Then it send its schedule to select receiver nodes. If it has no data to send then it gives up the time-slot and the data set (DS) is checked whether other nodes want to send their data. In step 10-18, if absolute winner belongs to one-hop neighboring nodes and there is no data to send then it gives up the time-slot otherwise it consults from one-hop neighboring nodes to switch either in receive state or in sleep state. In step 19-31, the inconsistency problem is handled where if the nodes which come in two-hop neighborhood of absolute winner and alternate winner, will miss the transmission from alternate winner.

Because what happens here is that if the absolute winner has not destined traffic to that node and it has gone to sleep state for that time-slot. Now if however it happens that it is the intended receiver of the alternate winner then it will miss the transmission. But this step handle this case via one-hop neighboring nodes schedules information which consults from them and then either switch in receive state or in sleep state. And the final step 32-42 tells about need transmitter in data set (DS) which uses other nodes time-slot to send their data when absolute winner has no data to send. This results in channel utilization and also reuse of time-slots that leads to higher throughput.

IV. COOPERATIVE MIMO COMMUNICATION

In co-operative MIMO communication, the nodes co-operate in transmission of their data which results more energy optimization rather than direct transmission of the data to the destination node. Here, a group of nodes or a set of nodes called one-hop set (OHS) are formed based on their short distance from each other. If the distance of some nodes is more than other nodes within this set then those nodes are not included in it. Now the node that is not selected in previous round and not reached its counter to a limit value, will be selected as monitor node for that set because to be select a node as monitor node we have to keep in mind that the same node is not selected every time. Here is the figure which describes it more clearly:

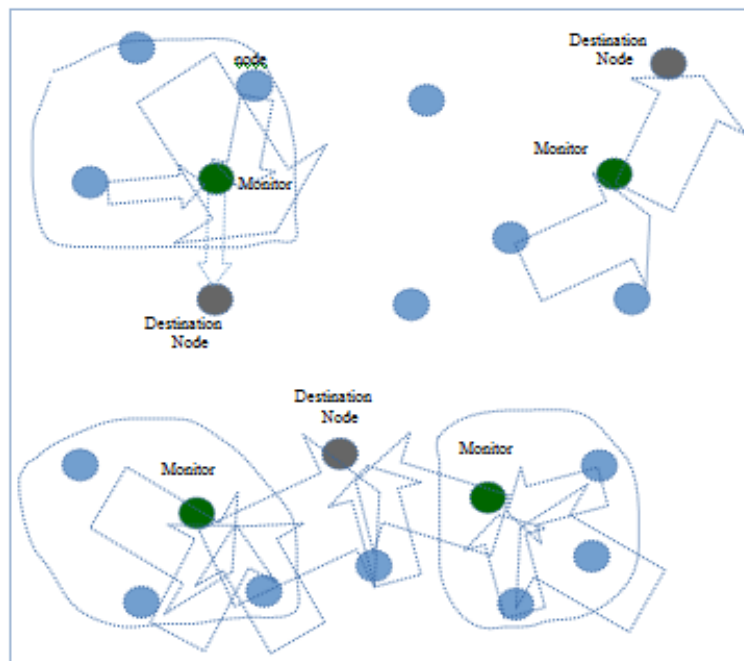


Figure 9: Co-operation of nodes

Monitor nodes are those that can transmit all the gathered data to other monitor nodes or to the final destination node. If a node is selected as monitor node and in next round it is selected again then in comparison to other nodes its energy will go down. So in order to maintain energy consumption of all the nodes these monitor nodes are selected in such way that all the nodes have to be given $1/N$ probability in that set. It may possible that some nodes are near destination node then there is no need to transmit their data first to a monitor node and then to the destination node. They can simply transmit their data to the destination node. There may be other problems like a node has to transmit its data but no nodes among its one-hop set has data to send then it may transmit its data to the nearest monitor node or by co-operating from nearest nodes it can transmit its data which is clear from above figure. The algorithmic description is given as follow :

Let N_t is the number of transmitters selected to transmit the data at any particular time-slot, M_n is the monitor node, and D_n is the destination node then

1. Begin
2. Select all the transmitters N_t
3. Select a monitor node M_n
4. PAR for $i=0$ to $i<N_t$
5. N_t .sendData
6. M_n .collectData
7. while $M_n \neq D_n$
8. Again select a monitor node M_n
9. Forward the data to that monitor node
10. End.

If monitor nodes are away from destination node means long haul transmission is needed then monitor nodes can forward their data to other monitor node which can be chosen in such a way so that all the nodes have equal probability to be chosen. These node acts as relay nodes.

V. CONCLUSION

In MIMO section the algorithm is more efficient than other protocol because it makes all the other nodes to switch in sleep mode that are not involving in any 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 then the current time-slots are used by another nodes to transmit their data. It provides not only collision-free transmission and energy-efficiency but also higher throughput by utilizing time-slots of other nodes that have no data in particular time-slots. Thus we can say no time-slot is going to be waste. In co-operate MIMO the energy efficiency is achieved by co-operation of monitor nodes which acts like relay nodes and make co-operative transmission possible. It reduces the energy-consumption in comparison to direct transmission of data.

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