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ENERGY CONSUMPTION IN WIRELESS SENSOR NETWORKS

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INTRODUCTION

The energy issue in the wireless sensor network is one of the biggest challenges, because the sensor has a limited source of power which is also hard to replace or recharge. For example: sensors in the battle field, sensors in a large forest...etc.,

Why limited source of energy?

- Inexpensive nature
- Limited size and weight
- Redundant nature

Sources of Energy Consumption

i. Useful energy consumption

Transmitting or receiving data, Processing query request, forwarding queries and data to the neighbors.

ii. Wasteful energy consumption

- Idle listing to the channel “waiting for possible traffic”.
- Retransmitting because of collisions “example,. two packets arrived at the same time at the sane sensor”.
- Overhearing “when a sensor received a packet doesn’t belong to it”.
- Generating and handling control packets.
- Over-emitting “when a sensor received a packet while it is not ready.

Energy Consumption Approaches

Three main approaches in Wireless Sensor Network for energy consumption [14] [22] [30] [37],

- Duty Cycling
- Data-driven approach
- Mobility

Duty Cycling

Duty cycling is mainly focused on the networking subsystem. The most effective energy-conserving operation is putting the radio transceiver in the (low-power) sleep mode whenever communication is not required. Ideally, the radio should be switched off as soon as there is no more data to send/receive and should be resumed as soon as a new data packet becomes ready. In this way nodes alternate between active and sleep periods depending on network activity. This behavior is usually referred to as duty cycling and duty cycle is defined as the fraction of time nodes are active during their lifetime. As sensor nodes perform a cooperative task, they need to coordinate their sleep/wakeup times. A sleep/wakeup scheduling algorithm thus accompanies any duty cycling scheme. It is typically a distributed algorithm based on which sensor nodes decide when to transition from active to sleep, and back. It allows neighboring nodes to be active at the same time, thus making packet exchange feasible even when nodes operate with a low duty cycle (i.e., they sleep for most of the time). Duty-cycling schemes are typically oblivious to data that are sampled by sensor nodes.

As shown in Figure 1, duty cycling can be achieved through two different and complementary approaches. From one side it is possible to exploit node redundancy, which is typical in sensor networks, and adaptively select only a minimum subset of nodes to remain active for maintaining connectivity. Nodes that are not currently needed for ensuring connectivity can go to sleep and save energy. Finding the optimal subset of nodes that guarantee connectivity is referred to as topology control.

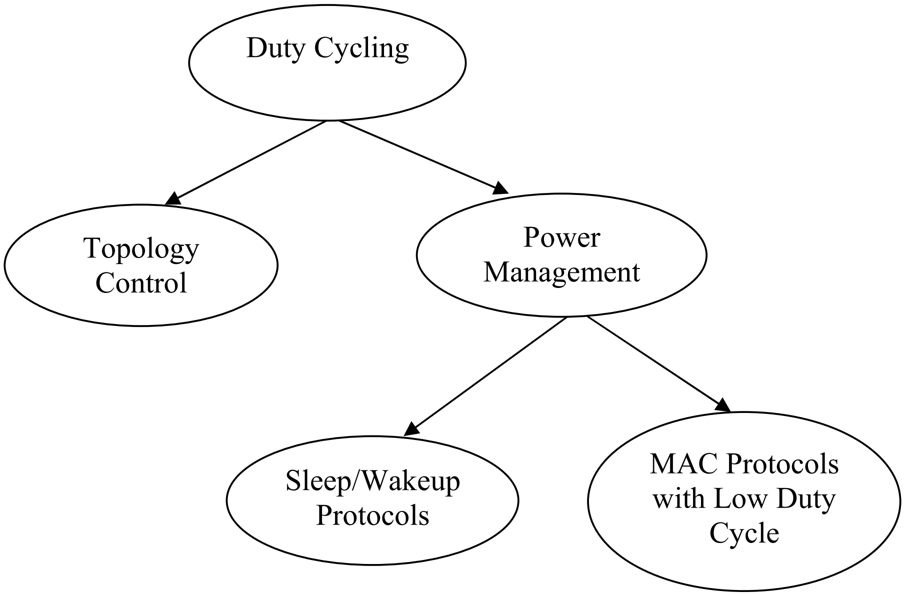


Figure 1 Taxonomy of Duty Cycling for Energy Conservation

Throughout will refer to duty cycling operated on active nodes as power management. Therefore, topology control and power management are complementary techniques that implement duty cycling with different granularity. Power management techniques can be further subdivided into two broad categories depending on the layer of the network architecture they are shown in Figure 1, power management protocols can be implemented either as independent sleep/wakeup protocols running on top of a MAC (Medium Access Control) protocol (typically at the network or application layer) or strictly integrated with the MAC protocol itself. The latter approach permits to optimize medium access functions based on the specific sleep/wakeup pattern used for power management. Independent sleep/wakeup protocols permit a greater flexibility as they can be tailored to the application needs and in principle can be used with any MAC protocol [14] [30] . MAC protocols that have been designed for typical ad hoc networks have primarily focused on optimizing fairness and throughput efficiency, with less emphasis on energy conservation. Most MAC protocols for sensor networks are to reduce the idle power consumption by setting the sensor radios into a sleep state as often as possible.

Data-driven Approach

Data-driven approaches can be used to improve the energy efficiency even more. In fact, data sensing impacts on sensor nodes energy consumption in two ways:

- **Unneeded samples**: Sampled data generally has strong spatial and/or temporal correlation, so there is no need to communicate the redundant information to the sink.
- **Power consumption of the sensing subsystem**: Reducing communication is not enough when the sensor itself is power hungry.

In the first case unneeded samples result in useless energy consumption, even if the cost of sampling is negligible, because they result in unneeded communications. The second issue arises whenever the consumption of the sensing subsystem is not negligible. Data driven techniques presented in the following are designed to reduce the amount of sampled data by keeping the sensing accuracy within an acceptable level for the application.

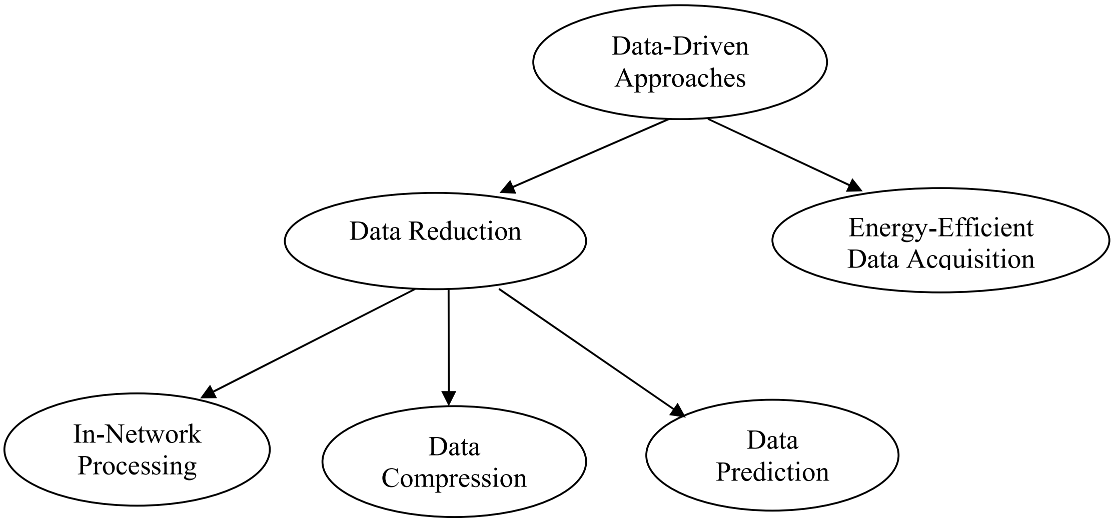


Figure 2 Taxonomy of Data-Driven Approach for Energy Conservation

Data-driven approaches can be divided according to the problem they address. Specifically, data-reduction schemes address the case of unneeded samples, while energy-efficient data acquisition schemes are mainly aimed at reducing the energy spent by the sensing subsystem. However, some of them can reduce the energy spent for communication as well. Also in this case, it is worth discussing here one more classification level related to data-reduction schemes, as shown in Figure 2. All these techniques aim at reducing the amount of data to be delivered to the sink node. However the principles behind them are rather different. In-network processing consists in performing data aggregation (example, computing average of some values) at intermediate nodes between the sources and the sink. In this way, the amount of data is reduced while traversing the network towards the sink. The most appropriate in-network processing technique depends on the specific application and must be tailored to it.

As data aggregation is application-specific. The interested reader can refer to for a comprehensive and up-to-date survey about in-network processing techniques. Data compression can be applied to reduce the amount of information sent by source nodes. This scheme involves encoding information at nodes which generate data and decoding it at the sink. There are different methods to compress data. As compression techniques are general (i.e. not necessarily related to WSNs), will omit a detailed discussion of them to focus on other approaches specifically tailored to WSNs.

Data prediction consists in building an abstraction of a sensed phenomenon, i.e. a model describing data evolution. The model can predict the values sensed by sensor nodes within certain error bounds and reside both at the sensors and at the sink. If the needed accuracy is satisfied, queries issued by users can be evaluated at the sink through the model without the need to get the exact data from nodes. On the other side, explicit communication between sensor nodes and the sink is needed when the model is not accurate enough, i.e. the actual sample has to be retrieved and/or the model has to be updated. Data prediction reduces the number of information sent by source nodes and the energy needed for communication as well.

Mobility

In case some of the sensor nodes are mobile, mobility can finally be used as a tool for reducing energy consumption (beyond duty cycling and data-driven techniques). In a static sensor network packets coming from sensor nodes follow a multi-hop path towards the sink(s).

Thus, a few paths can be more loaded than others, and nodes closer to the sink have to relay more packets so that they are more subject to premature energy depletion (funneling effect). If some of the nodes (Including, possibly, the sink) are mobile, the traffic flow can be altered if mobile devices are responsible for data collection directly from static nodes. Ordinary nodes wait for the passage of the mobile device and route messages towards it, so that the communications take place in proximity (directly or at most with a limited multi-hop traversal). As a consequence, ordinary nodes can save energy because path length, contention and forwarding overheads are reduced as well.

In addition, the mobile device can visit the network in order to spread more uniformly the energy consumption due to communications. When the cost of mobilizing sensor nodes is prohibitive, the usual approach is to "attach" sensor nodes to entities that will be roaming in the sensing field anyway, such as buses or animals.

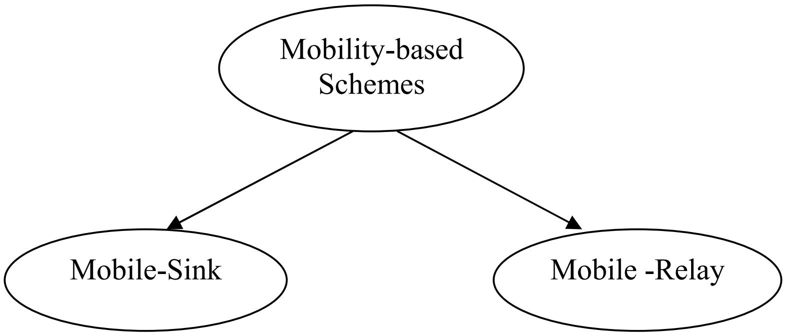


Figure 3 Taxonomy of Mobile-based Energy-Conservation Schemes

As shown in Figure 3, mobility-based schemes can be classified as mobile-sink and mobile-relay schemes, depending on the type of the mobile entity. It is worth pointing out here that, when considering mobile schemes, an important issue is the type of control the sensor-network designer has on the mobility of nodes.

Mobile nodes can be divided into two broad categories: they can be specifically designed as part of the network infrastructure, or they can be part of the environment. When they are part of the infrastructure, their mobility can be fully controlled and are, in general, robotized. When mobile nodes are part of the environment they might be not controllable. If they follow a strict schedule, then they have a completely predictable mobility (example, a shuttle for public transportation). Otherwise they may have a random behavior so that no reliable assumption can be made on their mobility. Finally, they may follow a mobility pattern that is neither predictable nor completely random. For example, this is the case of a bus moving in a city, whose speed is subject to large variation due to traffic conditions. In such a case, mobility patterns can be learned based on successive observations and estimated with some accuracy.

Energy Efficient MAC Protocols for WSNs

A wide range of energy efficient MAC protocols are described briefly [5] [13] [16] [28] [37] [38], which are categorized into contention-based, TDMA-based, hybrid and cross layer MAC protocols according to channel access policy are represented in Figure 4. Contention-based MAC protocols which are mainly based on the Carrier Sense Multiple Access (CSMA) or Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) require no coordination among the nodes accessing the channel. The core idea is when a node needs to send data it will compete for the wireless channel. Colliding nodes will back off for a random duration of time before attempting to access the channel again. The typical contention-based MAC protocols are S-MAC (Sensor-MAC), T-MAC (Timeout-MAC) and U-MAC (Utilization-MAC). TDMA-Based MAC Protocols in contrast to contention-based MAC protocols, the scheduling based TDMA technique offers an inherent collision-free scheme by assigning unique time slot for every node to send or receive data. The first advantage of TDMA (Time Division Multiple Access) is that interference between adjacent wireless links can be avoided. Thus, the energy waste coming from packet collisions is diminished. The Second advantage of TDMA can solve the hidden terminal problem without extra message overhead because neighboring nodes transmit at different time slots.

Main TDMA-based MAC protocols [24] include μ-MAC (Energy-efficient MAC), DEE-MAC (Dynamic Energy Efficient MAC), SPARE MAC (Slot Periodic Assignment for Reception MAC). Besides Hybrid contention-based, TDMA-based MAC and some hybrid MAC protocols have been recently proposed which have the advantages of both contention-based MAC and TDMA-based MAC protocols. All these protocols divide the access channel into two parts. Control packets are transmitted in the random access channel, while data packets are transmitted in the scheduled access channel. Compared with the contention-based MAC protocols and the TDMA-based MAC protocols, the hybrid protocols can obtain higher energy saving and offer better scalability and flexibility. The hybrid MAC protocols comprise Z-MAC (Zebra MAC), A-MAC (Advertisement-based MAC) and IEEE 802.15.4.

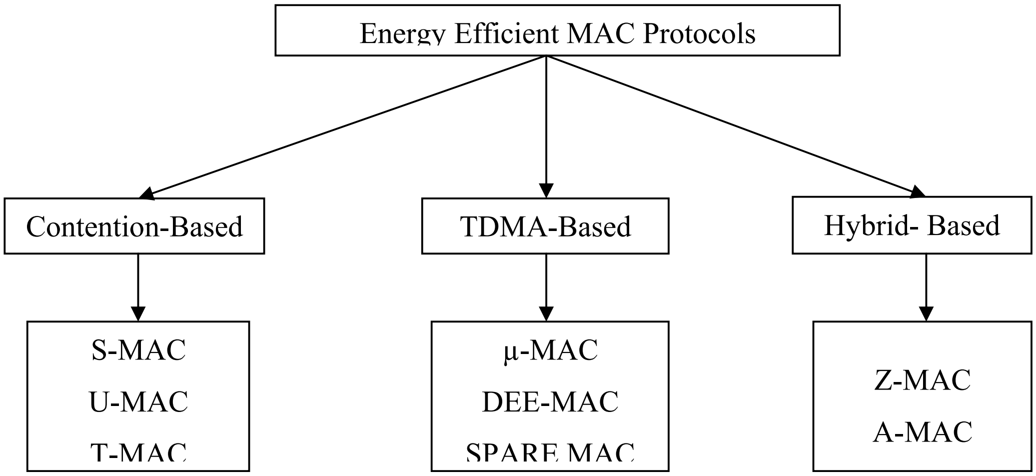


Figure 4 Classification of MAC protocols

Basic Idea for Packet Forwarding

Let us consider a sensor network where sensor nodes periodically send messages to a sink node through a multihop transmission. The basic idea of the packet forwarding is to split the messages sent by the source nodes so that a reduced number of bits are transmitted by each forwarder node [39]. In order to better understand the main idea, let us consider the example in Figure 5. Nodes A and B have to forward a packet to the sink S and can do it through nodes P, Q, and R, which are all in the coverage range of A and B.

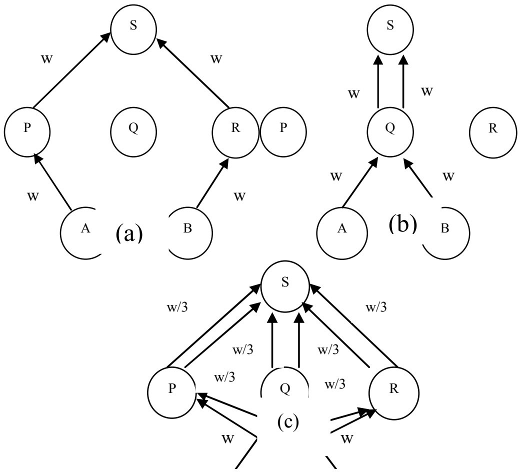


Figure 5 Forwarding examples

(a) Normal forwarding with different next-hops

(b) Normal forwarding with the same next-hop

(c) Forwarding after splitting.

If a normal forwarding scheme is adopted, two cases can be distinguished. Case i) A and B select different next-hop nodes in Figure 5(a).This happens with probability 2/3. Case ii) A and B select the same next-hop node in Figure 5(b).This happens with probability 1/3.

If there are "ω"bits for each packet, the maximum number of bits transmitted by a node belonging to the set {P, Q, R} is bits in the case i) and "2ω" bits in the case ii).1 Let us now assume that each node in the set {P, Q, R} knows that A and B have three possible next-hops and that a different forwarding scheme is adopted, as shown in Figure 5(c). In particular, when P, Q, and R receive a packet, they split it and send to the sink only a part (for instance, ω/3 bits each). In this case, P, Q, and R have to transmit at most 2/3 ω bits each.

If compare two forwarding methods, can conclude that the last one reduces the maximum number of bits transmitted by a node belonging to the set {P, Q, and R}. More precisely, the reduction factor is $1 - \frac{2}{3} = \frac{1}{3}$ when compare the splitting procedure with the procedure shown in case i), and $1 - 1/3 = \frac{2}{3}$when the splitting procedure is compared to the procedure shown in case ii).

Case i) Probability value, P (A) + P (B) = 1

1 – P (A) = P (B)

1 – 2/3 = P (B)

1/3 = P (B)

Case ii) Probability value, P (A) + P (B) = 1

1 – P (A) = P (B)

1 – 1/3 = P (B)

2/3 = P (B)

This example shows that although the total amount of transmitted bits does not change (2ω bits are transmitted anyway, either with or without splitting), by splitting a packet it is possible to reduce the maximum number of transmitted bits per node and therefore the mean energy that each node consumes for the transmission. Accordingly, the lifetime of a sensor network increases as the energy consumption is more distributed among the nodes.

Finally, it can be observed that if a perfect balancing is possible, which occurs when the number of next-hop node is a factor of the number of transmitted messages (i.e., the number of messages is exactly divisible by the number of next-hops), the energy consumed by nodes will be the same either with or without splitting. However, if this is not the case, using a splitting technique makes the number of forwarded bits significantly reduced. For instance, let us consider Figure 4.5(c) when N = 17 messages of ω =120 bits are sent. In this case, without splitting, at least one of the nodes P, Q, R will forward six messages (i.e., 120*6 = 720 bits), while using a splitting technique, each message can be split into three components of 40 bits each, so that 40*17 = 680 bits are forwarded. Therefore, when using splitting, the maximum number of transmitted bits per node is reduced by about 6%.

The above difference increases if consider that a node can forward seven messages out of 17 (in this case, have a reduction of 8%). Moreover, the reduction increases if the ratio “message length over number of components” decreases (i.e., if the number of available next-hop nodes are increases).

It is worth remarking that the splitting procedure has to be performed in a simple manner and consequently with low energy consumption, so that the sink can recombine the original packet maintaining at the same time the overhead needed to split the packet as small as possible. Furthermore, reliability should be considered as well. In fact, when classical splitting techniques are adopted (example, simple packet division into chunks), the probability that the original packet cannot be reconstructed increases.

Forwarding Technique based on Chinese Remainder Theorem 1

The Chinese Reminder Theorem is an ancient but important calculation algorithm in modular arithmetic. In its basic form, the Chinese remainder theorem will determine a number *n* that when divided by some given a divisor leaves given remainders [1] [2] [39].

Theorem 1

Let the numbers n_1, n_2 and m_1, m_2 be a positive integers. Two simultaneous congruence’s formulated as, $n = n_1 \pmod{m_1}$ and $n = n_2 \pmod{m_2}$ are only solvable when $n_1 = n_2 \pmod{\gcd(m_1, m_2)}$. The solution is unique modulo LCM (m_1, m_2). When m_1 and m_2 are co prime their gcd is 1. By convention, $a = b \pmod 1$ holds for any a and b.

Let us consider one example,

$N = 4 \pmod 5$

$N = 5 \pmod{11}$

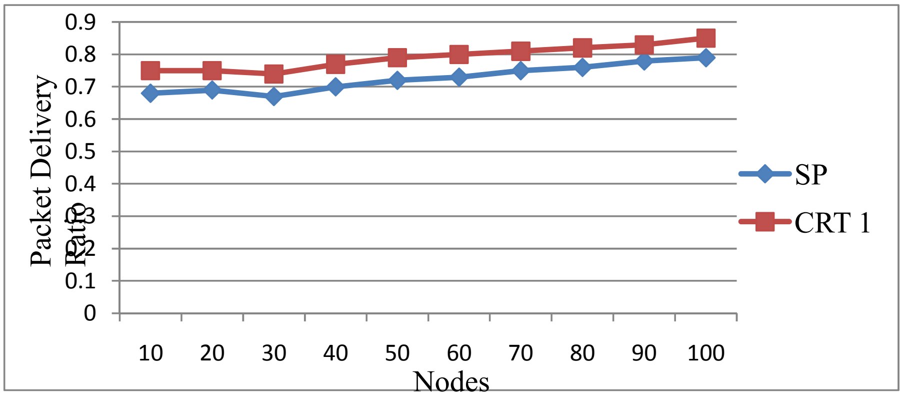
It is simple to prove that, $M = 5 * 11 = 55$, and $m_1 = 5$, $m_2 = 11$(the moduli). $c_1 = 4$, $c_2 = 5$ (the constants from the congruence's).

Performance Analysis

Wireless Sensor Network performance is evaluated by using following metrics: Packet Delivery Ratio (PDR), End-to-End Delay, Packet Lost, Throughput and Energy Efficiency.

Packet Delivery Ratio

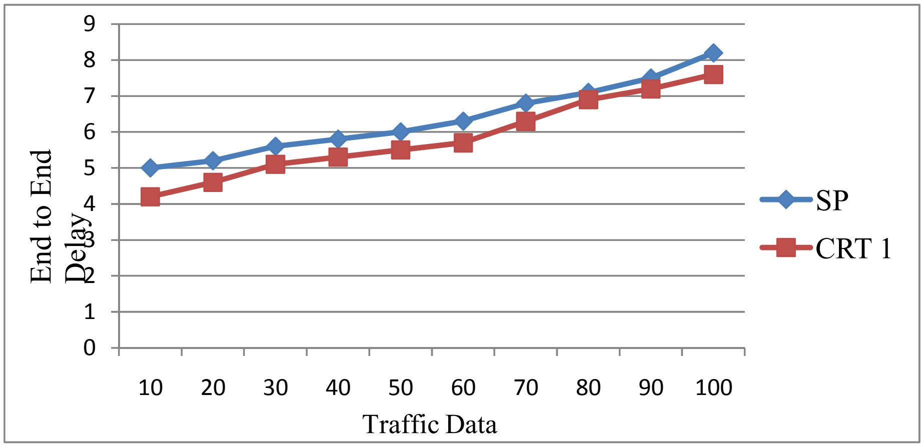
Packet Delivery Ratio (PDR) is the ratio of total number of packets received successfully and the total number of packets transmitted. Packet Delivery Ratio has represented in Graph 1. It represented the values for both Shortest Path (SP) and Chinese Remainder Theorem 1 (CRT 1) approaches. Packet delivery ratio is 0.79 when using SP approach at the same time the packet delivery ratio is 0.85 when using CRT 1 approach. Finally, the maximum of packet delivery ratio has achieved by using CRT 1 approach.



Graph 1 Nodes Vs Packet Delivery Ratio

End to End Delay

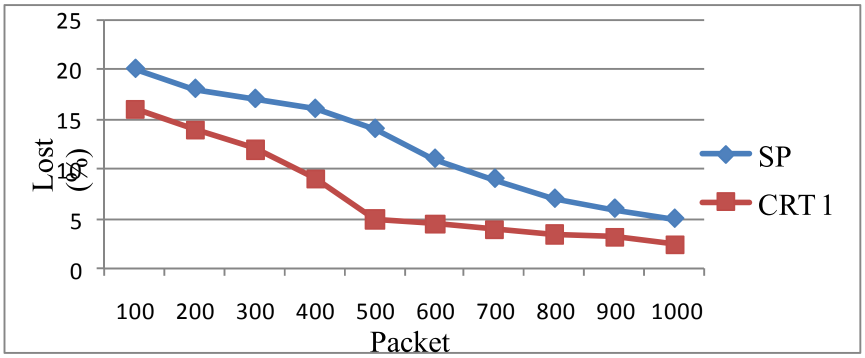
End to End delay refers to the time taken for a packet to the transmitted across a network from source to destination. End to End delay has represented in Graph 2. In Shortest Path (SP) approach, when using 500 packets get 8 milliseconds delay and using 100 packets get 5 milliseconds delay. In Chinese Remainder Theorem 1 (CRT 1) approach, when using 500 packets get 7.5 milliseconds and using 100 packets get 4.2 milliseconds delay. Finally, the minimum end to end delay has achieved by using CRT 1 approach.



Graph 2 Traffic Data Vs End to End Delay

Packet Lost

Packet lost occurs when one or more packets of data travelling across a computer network fail to reach their destination. It is calculated based on the total number of packets dropped during the simulation.

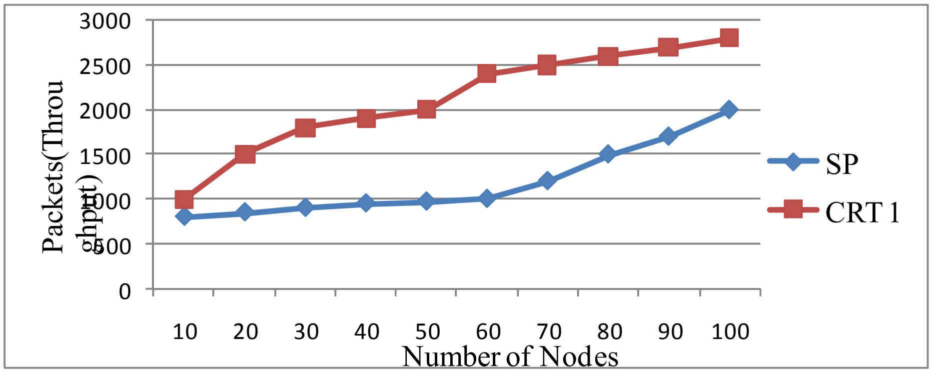


Graph 3 Packet Size Vs Lost

Packet lost is shown in Graph 3. In SP approach, when using 1000 packets for transmission achieve 5 percentage of packet lost and using 500 packets for transmission achieve 14 percentage of packet lost. In CRT 1 approach, when using 1000 packets for transmission achieve 3 percentage of packet lost and using 500 packets for transmission achieve 5 percentage of packet lost. Finally, the minimum packet lost has achieved by using CRT 1 approach.

Throughput

Throughput is the average rate of successful message delivery over a communication channel. The throughput is usually measured in bits per second and sometimes in data packets per seconds.



Graph 4 Number nodes Ns Packets

Throughput ratio is represented in Graph 4. In Shortest Path (SP) approach, 50 nodes delivered the 1000 data packets per second at the same time 100 nodes delivered the 2000 data packets per second. In Chinese Remainder Theorem 1 (CRT 1) approach, 50 nodes delivered the 2000 data packets per second at the same time 100 nodes delivered the 2800 data packets per second. Finally, maximum of throughput has achieved by using CRT 1 approach.

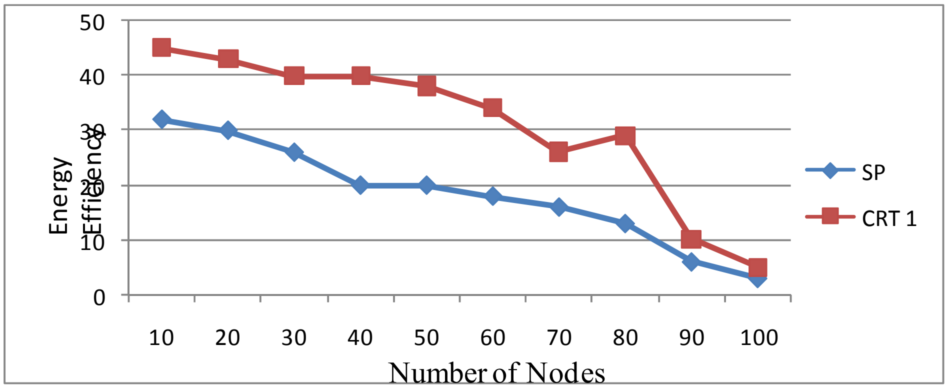
Energy Efficiency

Energy efficiency is defined as the total unused energy level of nodes in the network. Energy efficiency level is represented in both the Shortest Path (SP) and Chinese Remainder Theorem 1 (CRT 1) approaches in Graph 5. SP approach has achieved 33% energy efficiency. But, the CRT 1 approach has achieved 45% energy efficiency. Finally, maximum amount of energy efficiency has achieved by using CRT 1 approach.

Table 1 Performance comparison between SP and CRT 1

Packet Delivery Ratio (PDR)		End-to-End Delay		Packet Lost		Throughput		Energy Efficiency	
SP (%)	CRT 1 (%)	SP (%)	CRT 1 (%)	SP (%)	CRT 1 (%)	SP (bits)	CRT 1 (bits)	SP (%)	CRT (%)
68	75	5	4.2	20	16	800	1000	32	45
69	75	5.2	4.6	18	14	850	1500	30	43
67	74	5.6	5.1	17	12	900	1600	26	40
70	77	5.8	5.3	16	9	950	1900	20	40
72	79	6	5.5	14	5	970	2000	20	38
73	80	6.3	5.7	11	4.5	1000	2300	18	34
75	81	6.8	6.3	9	4	1200	2300	16	26
76	82	7.1	6.9	7	3.5	1500	2500	13	19
78	83	7.5	7.2	6	3.2	1700	2600	6	10
79	85	8.2	7.6	5	2.5	2000	2800	3	5

Table 1 shows the comparative values for both Shortest Path and Chinese Remainder Theorem 1. It represents the following results such as, Packet Delivery Ratio (PDR), End to End Delay, Packet Lost, Throughput and Energy Efficiency.



Graph 5 Number of Nodes Vs Energy Efficiency

According to CRT theorem 1, in Wireless Sensor Network, the original data packets are split into a number of sub-packets equal to the number of disjoint paths from source to destination. This approach has applied sequentially in that network. For that reason it has taken more computational time. To overcome this problem CRT theorem 2 is proposed.

CONCLUSION

In this paper a new forwarding algorithm based on the Chinese Remainder Theorem has been introduced. This proposed technique significantly reduces the energy consumed for each node and consequently improves network life time in Wireless Sensor Networks. Computation time is also reduced by this approach. Simulation results demonstrate that the energy efficient adaptive multipath routing scheme achieves much higher performance than the classical routing protocols.

Future Enhancement

1. CRT Technique can be suggested for various classes of networks.
2. Packet Splitting technique with security mechanism can be suggested for secure communication.

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