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A Survey on Energy-Efficient Management in Wireless Sensor Networks

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Abstract –

Lifetime of Wireless Sensor Networks (WSNs) depends upon power consumed from resources *viz.* battery energy. Energy consumed by communication circuits will be high. Therefore energy consumed on transmission and receiving of data or communicating between each node mainly depends on channel state of wireless links. If channel conditions are good, communication can be done at low power consumption, leading to extension of network and battery lifetime. This issue is popular as there are many protocols for solving this. This article summarises some problems like Power Management, Data Aggregation, Channel Aware Opportunistic Transmission, Clustering Mechanism of nodes and Energy-Efficient management in Unstructured in WSNs. These are classified with different design criteria. There are many solutions for each problem. Here we give a survey on best reliable solution for each problem.

I INTRODUCTION:

Sensor networks consist of dense wireless small & low cost sensors. They are composed of systematically distributed sensors, which are sensitive to environment and capable of communicating with each other. These sensors are equipped with both data processing and communication capabilities. They measure different parameters from environment and transform them into electrical signals and disseminate data to us. Dissemination schedule generated primarily by the root node & propagated down the tree as part of a control event. The root node serves as entry point to the sensor network and integrates the sensor network with external wired network.

There are four major components in a Wireless Sensor Networks (WSNs):- an assembly of localised sensors, interconnecting network, a central point of information clustering & a set of computing resources. These computing resource present at the central point handle data correlation, event trending, status querying and data mining.

II. APPLICATIONS:

WSNs are convenient for monitoring and controlling of physical environments from remote locations. They can operate & collect information from unattended harsh environments (like mid sea, nuclear explosions etc.). Other applications include those in industry, medical science, home automation, consumer areas and for military purpose.

These WSNs get power from batteries; therefore they have high requirement for long battery life. The concerns for energy from battery in WSNs have inspired several energy efficient protocols, processors, designs and algorithms. Efficient power management leads to longer battery life i.e., system life will be much extended by applying many energy efficient techniques. However there exist many problems leading to energy reduction in WSNs. These are discussed below in the section II. We also discuss several approaches to manage the Energy-Efficient problems in the section III.

III. PROBLEMS IN WSNs:

A. Energy management in circuits*:*

In WSNs major part of energy is consumed by communication circuits. So communication functions should take place only when it is needed. In Dynamic Power Management (DPM) system shuts down the sensor nodes where there is no activity and resumes when needed [15], [18]. The main objective is to save energy. The sensors communicate in short packets which require large activated energy. Hence, very careful implementation of DPM is required. There are many DPM schemes, but when compared to all Operational System, Directed Power Management aspect is the most useful one.

B. Channel-Aware Opportunistic Transmission Scheduling for Energy-Efficient Wireless Links:

In wireless sensor networks and many data services, demand of small scale devices with low capability constraints resulted in effective network resource management. These wireless devices mostly contain less-infrastructure networks. There will be no continuous power in these networks as the capability of mobility varies; in connecting to power supply reduces. Variation of mobility tends to affect signal quality. Result is variation of bit error rate over small time interval. These devices use battery energy to operate. But energy consumption in these batteries is the most significant issue in present wireless communication networks
The channel conditions are time variant and radio channel experiences both small scales fading due to multipath and large scale fading which occur due to shadowing [1]. Multipath fading, a deterministic phenomenon, depends upon node deployment and the layout and topology of their surrounding environment. The signal level tends to attenuate substantially on displacement of receiver and transmitter by about half a wavelength. In case of shadowing large obstacles create shadow zones which tend to deviate signals from mean value, if a receiver happens to enter these shadows. As these are having time-varying characteristics, to achieve good energy utilization in communication one need to find good channel conditions while transmission.

A preferable choice to satisfy these conditions and also to prolong battery life is the use of distributed opportunistic transmission scheduling and optimal time instant method to find optimal time for transmission. According to these two techniques we can delay our transmission until best channel is found i.e., until channel is found with good conditions and tolerable time deadline and certain power level at the receiver. By using the Energy-Efficient Opportunistic Transmission Scheduler (E^2OTS) [21] this can be solved.

C. Data aggregation:

In WSNs, sensor nodes are much dense and data sampled by them have more redundancy. Data aggregation is an effective method to minimize number of transmissions. Data are aggregated to eliminate redundant transmission & provide fused information to the base station. This transmission is done in energy efficient manner with minimum data latency. The network lifetime is also enhanced. Data sampled by different sensors is however different and cannot be aggregated together to form a single packets. Now-a-days data aggregation is mostly done using static routing which cannot forward packets according to network state or packets type. So this static routing is unfavourable for data aggregation. To exploit these correlations, it is suggested that the data aggregation can be done by simple data fusion, introduced by Heinemann et al [10]. Fusion is categorized as low, intermediate or high, depending on the processing stage at which fusion takes place. Low level data fusion combines several sources of raw data to produce new raw data, which can be more informative and synthetic than the original inputs. This fusion can be done at intermediate nodes by SUM, MAX, MIN, AVG, etc., and thus we can save energy by reducing more data transmissions. There are many data aggregation schemes to save energy in WSNs like majority voting, complete agreement weighted voting etc. [3], [4], [6], [9], [10], [20].

D. Clustering Mechanism for Energy-Efficient*:*

In WSNs, sensor nodes must report monitored information to central node known as sink. As these nodes are battery dependent it is very difficult to charge these batteries often. Efficient routing protocols are needed for reporting information, to achieve high delivery ratio and to prolong network life time. There are three different categories of routing protocols: chain based, tree-based and cluster based [8]. Cluster heads, the controller nodes for clusters, are responsible for controlling the operation of the sensor node in the cluster by setting their configuration parameters, for aggregating the sensor readings collected from the cluster & storing the result or sending it to the sink or some higher level cluster head. In these three methods cluster head becomes a bottleneck for message delivery and it quickly exhaust its battery energy. By using the passive clustering technique, [2] this can be solved because in this case each node is connected with external cluster state, where cluster head and gateway are major participants in packet delivery. Here main challenge is to select proper cluster heads and gateways from nodes. But these cluster heads generally consume more battery energy than other nodes so that routing path may be destroyed. Cluster head also consumes more energy, if connected with poor quality link. Study of passive clustering technique proposes a link-aware clustering mechanism (LCM) to support energy efficient routing in WSNs.

E. Energy-Efficient Coverage for Unstructured WSNs:

WSNs are of structured and unstructured types. The unstructured networks are mainly used in environments where humans cannot enter like deep sea and nuclear explosion areas. These contain a dense collection of sensor nodes placed in the field randomly. They are dependent upon battery energy which cannot be recharged easily. Energy efficiency is the main problem in unstructured WSNs. Present day techniques for global solution involve many stochastic algorithms like Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) algorithms [13], [16], [17], [19]. However these require more computational time than Greedy method. (In Greedy algorithm, a node decides about the transmission path based on the position of its neighbours). Hence we use new algorithm known as Jenga-Inspired Optimization Algorithm (JOA), which solves Energy-Efficient Coverage problem.

III. SOLUTIONS:

A. Operational System Directed Power Management aspect:

In this aspect DPM is combined with Optimal Geographic Density Control (OGDC) [7] keeping minimum number of nodes in active state. The network life time is prolonged. Saved energy should always be greater than that of expended transition energy. We have to consider the energy state of consumption when system turns components ON/OFF to reduce energy. In this DPM+OGDC scheme all sleeping states of nodes are not useful. Dynamics of sensing coverage versus time is stimulated and is proved that OGDC provides 95% coverage. So, DPM+OGDC provides more life time of WSNs than mainly with DPM.

B. Energy-Efficient Opportunistic Transmission Scheduler $\mathrm{E^2OTS}$:

Main aim of this E^2OTS is to reduce transmission energy consumption of wireless devices. To achieve this condition there are two different approaches: 1) expected energy consumption minimization approach (E^2OTS -I) and 2) average energy consumption per unit of time (E^2OTS-II). Using distributed transmission scheduler ideal channel opportunities can be found. These proposed schedulers delay transmission until a good/ideal source is available for transmission. Transmission power reduces when channel conditions are good. By using the Shannon theorem (Eq.1) we can illustrate scheduler's problem:

$$R = Wlog_2\left(1+\frac{g.P_{Tx}}{N_oW}\right) \text{ --- } (1)$$

Where R is channel capacity, W - Channel bandwidth, g -channel power gain, P_{Tx} is transmitted power gain, N_o represents noise power spectral density. The channel conditions are checked for every specific time interval. Transmission is delayed until ideal channel is found. If no good channels are not found, then the delay reaches maximum. Here transmitter's communication module can set to sleep or idle between two sequential checks to save energy. Note, data transmission duration (T) should always be greater than coherent time. Else use of proposed approaches of E^2OTS will be presented.

$E^2OTS - I$:

In this approach two policies are used: - one Minimisation problem and other Multi threshold policy. In Minimization problem, scheduling is considered for one round to provide solution. Therefore total energy loss E_N for channel checks and power consumption P_N during T can be given as

$$E_N = P_NT + NE_c = \frac{\left(2^{\frac{R}{W}}-1\right)}{gN}N_oWT + NE_c$$

Where, $A = \left(2^{\frac{R}{W}} - 1\right)N_oW$ is constant under QoS and represents power of received signal. In Multi threshold policy we check each channel condition and decide whether transmission required or not, on comparing with a threshold. This also depends upon optimal stopping rule which decides transmission by checking each stage *j*. Summarised scheduling policy that minimizes energy consumption can be given as

$$\underline{\text{If}} \quad P_j \leq P^*_{th,j} \rightarrow transmit\ at\ j$$

$$\underline{\text{Else}} \quad \rightarrow postpone\ at\ j$$

Here P_j is the optimal transmission power, $P^*_{th,j}$ is the corresponding optimal threshold.

$E^2OTS - II$:

This is similar to first case having Minimization problem and Multi threshold policy but considered for L rounds. Therefore average energy loss per unit time can be expressed as

$$\frac{\sum_{l=1}^{L} E_{Nl}}{\sum_{l=1}^{L} T_{Nl}} \rightarrow \frac{E[E_N]}{E[T_N]}$$

Here total round duration $T_N = N_\tau + T$ & total summarized equation can be given as

$$\underline{\text{If}} \quad P_j \leq P^*_{th,j} \rightarrow transmit\ at\ j$$

$$\underline{\text{Else}} \quad \rightarrow postpone\ at\ j$$

C. Attribute-Aware Data Aggregation (ADA) scheme:

In this ADA scheme [24] the packets having same attribute can be made convergent as much as possible and are made to reduce number of transmissions to save energy. By using concept of packet attribute, identifying packets from heterogeneous sensors, they are arranged according to specific requirements. It is difficult to predetermine proper routing for each path, using dynamic routing protocol. This is borrowed from concept of potential in physics to adapt frequent variation of packet attribute distribution at each node. This scheme is used because we cannot predict each packet attribute at each node when events occur randomly. Here using concept of pheromone, this is left along the path to attract packets which are having same attribute. Packets should also be temporally convergent in order to meet each other at same nodes at same intervals. This increases performance of data aggregation scheme. Packets will be forwarded from one node to another node by force acting on packet p at node u based on potential between nodes.

$$F_{u\to v} = V(u) - V(v)$$

Packets transmitted to sink will be ensured by depth potential field. Force acting from node u to neighbour node $\Omega(u)$ in depth potential is given by

$$F_{u\to v}^{d} = D(u) - D(v)$$

Each packet enters and leaves pheromone τ at constant time. This pheromone increases after packets pass through it and evaporates with time. To reduce overhead, $\tau(v,\delta)$ will be updated as follows

$$\tau(v,\delta) = \rho * \tau(v,\delta) + I * \Delta\tau$$

I is an indicative function. When packet with attribute D reaches node v, I =1 and else I =0. Nodes with more intense pheromone have lower pheromone potential. Therefore pheromone potential is given as$V_p(u,\delta) = 1 - \tau(u,\delta)$. Pheromone potential field force between nodes is given as

$$F_{u\to v}^{P}(\delta) = V_P(u,\delta) - V_p(u,\delta)$$

Combining both depth potential and pheromone potential field to form a hybrid potential field, which ensures that packets reached sinks is more spatially convergent. This is given as

$$V_h(u,s) = (1-\alpha)V_d(u) + \alpha V_p(u,\delta)$$

$V_h(u,s)$ is potential value of hybrid field at node u with attribute δ. The force from node u to v in hybrid potential field is given by

$$F_{u\to v}^{h} = (1-\alpha)F_{u\to v}^{d} + \alpha F_{u\to v}^{p}(\delta).$$

Also by using adaptive driven timing control algorithm, one can improve temporal convergence. By using this scheme energy efficiency of the system can be increased.

D. Link-Aware Clustering Mechanism (LCM):

LCM considers node status and link conditions, which proposes a novel metric, called predicted transmission count (PTX) [22]. This evaluates channel heads and gateways candidates' suitability. This also considers transmit power, residual energy and link quality to derive the PTX of candidates. If PTX is high it indicates it is going to become a channel head or gateway node. Link reliability depends upon channel quality. If it is not good data delivery is likely to fail and retransmission takes place and consumes more energy. Channel associated with stable link is preferred to select channel head node or gateway node. LCM also uses expected transmission (ETX) to measure expected bi-directional transmission count of link. The ETX of the link e_{ij} can be defined as

$$ETX_{ij} = \frac{1}{p_{ij}^{f} \cdot p_{ij}^{r}}$$

Where p_{ij}^{f} and p_{ij}^{r} indicates forward and reverse delivery ratio between nodes s_i and s_j to determine data packet successfully received at recipient and acknowledgment of packet. For deriving PTX when node s_i receives messages from node s_j, one needs to write for q_{ij}

$$q_{ij} = \frac{E_i^{\mathrm{res}}}{ETx_{ij} \cdot E^{tx}(k, d_{ij})}$$

Where E_i^{res} is residual energy of the s_i, d_{ij} is distance between nodes, $E^{tx}(k, d_{ij})$ is energy consumed by node to transmit k-bit message over a distanced_{ij}. LCM considers both link quality and node status to construct a reliable routing path to guarantee report quality.

E. Jenga-Inspired Optimization Algorithm (JOA):

This JOA was inspired by Jenga, which is well-known board game. Sensors have to detect many events like temperature, pressure, heat and force, which occur at Point of Interest (PoI). Hence intensity will decrease if distance between PoI and sensors increases. In that case, another sensor node which is nearby will take turn to cover those events and increase WSNs life time. JOA is divided into two stages 1) Collecting position information from sensors and PoIs and storing them i.e., preparation and initialization 2) By collecting information of number of PoIs that can be covered by each sensor i.e., it has double loop. After this we can set number of adjustable parameters and threshold for smallest probability of detection at every PoI. We can also initialize a set to store optimal subset of sensors in every timeslot and initialize variable to store the final value of time slot i.e., lifetime of WSN for EEC [23].

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