Energy Efficiency in Internet of Things: An Overview

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Abstract: Internet of Things (IoT) is an emerging technology and energy consumption is one of the important issues. It is crucial because the devices are energy constrained. Battery operated sensors, actuators and everyday objects are connected to the internet. Significant progress has been made in this paradigm. This paper presents the issues and ways to minimize the energy consumption in IoT environment.

Key words: IoT, Devices, Conservation, Energy Efficiency, Protocols.

I. INTRODUCTION

The Internet of Things is a new paradigm. It combines technologies such as ubiquitous computing, pervasive computing, internet protocol, sensing technologies and communication technologies etc., the term was coined by Kevin Ashton in 1999. He imagined the world where Internet is connected to the physical world to enhance comfort, security and control of our lives. Since millions of devices are connected to the internet and the devices are energy constrained, energy is an important factor in IoT. In order to increase the life time of a sensor node, energy must be saved at different levels. This paper presents an overview of energy efficiency in IoT environment, and some ways to energy conservation.

II. ENERGY EFFICIENCY IN IOT

The term Energy Efficiency covers different aspects of a system in IoT. The most common aspects are as follows:

- **Energy per correctly received bit**: how much is spent to transport one bit of information from source to the destination.
- **Energy per reported event**: It is the energy spent to report one event.
- **Delay/energy trade-off**: the notion of urgent events and speed in reporting such events.
- **Network Lifetime**: The time in which it is able to fulfil its task.

A sensor node uses its energy to carry out functions such as acquisition, communication and data processing. Acquisition depends on the type of monitoring. Communication consumes more energy than other task. It covers in terms of emission and reception. Data processing is a technique in which an intermediate node is chosen to consolidate the sensor data streams from the source nodes to the sink node.

III. LITERATURE SURVEY

Algimantas et al. [5] proposed the energy efficient SSL protocol which ensured the maximum bandwidth and required level of security with minimum energy consumption. They explained the basic concept of the SSL protocol and proposed adaptive SSL protocol. They implemented the following security objectives in SSL protocol: confidentiality, integrity and availability. In order to achieve the security objective of SSL protocols, proper cryptography techniques were applied.
Fangxin Chen et al. [7] presented a comprehensive summing of topology control routing protocol and data link protocol. A good topology structure could improve efficiency of routing protocol. The data link protocol provided a basis for data fusion, target location and other aspects, thus prolong the survival time of the whole network. The authors explained energy collecting technologies like vibration energy, solar energy and wind energy. To sum up, the authors discussed the current situation of energy supply and management techniques of the wireless sensor network.

Gang Wu et al. [8] provided an energy efficient approach in both physical layer and deployment aspects. They also proposed a basic principle of energy efficient optimization. There are various energy related algorithms such as multi-level water filling or bi-section algorithms for optimization.

Hui Suo et al. [9] discussed the status of key technologies including encryption mechanism, communication security, protecting sensor data and cryptographic algorithms. They reviewed the above mentioned key technologies and adopted hop encryption protection. Finally, they analyzed security characteristics and requirements from four layers including perception layer, network layer, support layer and application layer.

Julien Beaudaux et al. [10] proposed a strategy to enable heterogeneous MAC duty-cycle configuration among nodes in the network. To implement the idea, the nodes were divided into disjoint subsets, each of them standing for a given duty-cycle configuration. In the proposed solution, the authors explained routing role and sleep depth. The former made MAC and routing layers cooperate, so that each node was able to know number of nodes above in the routing tree. The latter relied on applicative criteria to separate the nodes into different sleep-depth, represented as disjoint virtual layers.

Kyungmin Kim et al. [11] suggested energy efficient and reliable data automatic repeat request scheme to minimize transmission delay and energy consumption at the same time. The scheme consisted three aspects namely duplication retransmission prevention, congestion control and error notification.

Mallikarjun Talwar [12] outlined routing techniques and protocols for IoTs. Initially, the author explained the characteristics of routing protocols and some of the key challenges. Finally, the author explained a wide range of routing protocols like RPL, OLSR, AODV and PRoPHET.

Marcus et al. [13] proposed a new MAC protocol, called PaderMAC, for wireless sensor networks. PaderMAC principle was implemented using Tinyos and the MAC layer Architecture. The aim of this was to improve lifetime by further shortening energy consuming preambles.

Mohammed et al. [14] proposed an efficient cluster-based sleep scheduling for M2M communication network. In this system, devices were deployed and clusters were formed. All devices were assumed to have same energy. A number of devices were selected as Principal Cluster Heads (PCH). A number of devices made as Alternative Cluster Heads (ACH) providing fault tolerance to the PCH devices. The PCH selected number of devices in each cluster as active. These devices provided network coverage and remained in active state. The rest of the devices remained in active/sleep state. Thus, the energy consumption was lower compared to other methods.

Pallavi V S Katkar et al. [15] presented a survey on energy efficiency routing protocols in wireless sensor networks. They discussed the factor that influenced the routing protocols such as fault tolerance, node deployment, and energy consumption without losing accuracy and scalability. They also elaborated the characteristics of some of the protocols like Low Energy Adaptive
Clustering Hierarchy (LEACH), Power Efficient Gathering in Sensor Information System (PEGASIS), Power-efficient and Adaptive Clustering Hierarchy (PEACH), Threshold sensitive Energy Efficient sensor Network Protocol (TEEN), Energy Efficient Ant-Based Routing (EEABR) and Self-Organizing Protocol (SOP). Authors finally studied important issues of routing which influencing sensor network design.

Rongxing Lu et al. [17] illustrated an activity scheduling scheme for sensing coverage. In each round, a node selected a random timeout and listened to messages from neighbours before it expired. These messages contained the activity decision. A node decided to be active if its sensing range was fully covered by sensing ranges of a connected set of active neighbors.

Samia Abdullah et al. [18] proposed an architecture considering both routing algorithm and the message scheduling algorithm. Sensors were clustered into groups. It was following a cluster approach. Here, one set of sensor nodes called IoT subgroup, where every node could become the broker each time. Every time the node which is the broker takes the responsibility of aggregating the data from its nearby nodes and sends the data to the base station. Messages from sensor devices were analyzed. Based on the queue theory, messages were rearranged. How the message rearrangement affected the life time of IoT sensor network under routing protocol was also shown.

Satvir Singh et al. [19] presented a comprehensive survey on energy efficient routing protocol in wireless sensor networks. Authors also discussed the factors that influenced the design of routing protocols. They described many protocols.

Shyam Sundar et al. [20] explored the potential energy efficient reliable barriers with examples and suggested scheduling scheme as remedies. The scheme required time to be slotted and activity scheduling was done in rounds. In each round, a node selected a random timeout and listened to messages from neighbours before it expired. The node made its own activity decision and announced it to the neighbours by transmitting a message. The scheme involved local communication and generated a very small number of control messages, thus being energy efficient.

Zeeshan Abbas et al. [22] outlined a comprehensive survey on energy conserving issues and solutions. Using (3GPP) machine type communications like IEEE 802.11ah, Bluetooth, Low Energy and Z–wave, the authors tackled various operational aspects of IoT devices. The tackled issues were duty cycle, congestion, avoidance schemes, sleep and wakeup time and the selection of heterogeneous radio interfaces. The authors also proposed future research directions regarding energy conserving issues.

IV. ISSUES IN ENERGY CONSERVATION

Based on the above literature, the issues related to energy efficiency in IoT can be summed up in the following manner.

3.1 Idle Listening

Node in active mode is a major source of energy consumption. It is important to reduce wasted energy resources. It needs not to be in an active state. The awaiting ready to transmit data while not receiving or sending packets is called idle listening. There are different approaches to reduce the overall active time. The sleeping sensor nodes switch back to active mode after a certain time span or after the processing of a wake-up signal.
3.2 Collision
Collision occurs if nodes receive multiple data packets at the same time. Due to this, the received data is useless. Transmission process has to be repeated while energy is dissipated. Collision increases latency as well. These transactions could consume quite a lot of energy.

3.3 Over Hearing
High density sensor nodes lead to interferences with neighbour nodes during data conveyance. This is called over hearing. The nodes within reach have this particular problem. This leads to burn up energy resources owing to receiving and processing useless information.

3.4 Reduction of protocol overhead
The protocol header information depletes energy resources. Techniques for the reduction of the protocol overhead are adaptive transmission periods, cross-layering approaches and optimized flooding.

3.5 Traffic Fluctuation
Traffic can lead to congestion or high delays. If the network is working on its maximum capacity, congestion raises to extremely high level.

V. A STUDY ON ISSUES AND CHALLENGES IN ENERGY EFFICIENCY

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VI. WAYS OF ENERGY CONSERVATION

These are some of the ways to implement energy conservation in IoT based on the study.

6.1 Node activity management

There are two parts in node activity namely, sleeping scheduling and on-demand node activity. Sleep scheduling is the way to set the node to a sleeping mode and determine the time to wake up. This saves energy in idle time spans. Here, certain periods are determined in which the individual node is in sleeping mode.

On-demand node activity is not scheduled, but the node is by default in an active state with a simple functionality. If a wake-up signal is broadcasted, the neighbouring nodes within the area switch to active mode. After activation, the data transmission takes place. As the start-up signal does not have to be decoded, all surrounding nodes are switched on and for the most unnecessarily.

Devices are deployed and clusters are formed. An activity scheduling scheme [15] is also proposed for sensing coverage. This is done in rounds. In each round, a node selects a random timeout and listens to messages from neighbours before it expires. The messages contain decision to be active or not. A small amount of energy is needed to pass this type of messages. By reducing energy consumption at the node level, energy efficiency can be increased.

6.2 Data Aggregation and Transmission Process

The cost of transmitting data is higher than the data processing. It is beneficial to aggregate data within clusters. Clusters can reduce the amount of data, as the cluster heads are in-charge of monitoring and processing queries. It eases several of the energy dissipating effects. In this process, data which is coming from different sources is combined into a single data packet. This helps to reduce redundancy and to minimize the number of transmission.

Wireless transmission of data uses a large portion of the total energy. Incorporating power control into the transmission process could yield higher energy savings [21]. In short range applications, the transmission power, which is directly related to the data rate, and the circuit power should be carefully balanced to achieve high Energy Efficiency [6]. In order to achieve energy efficiency during transmission, optimization algorithms are used.

6.3 MAC Protocol

Energy is very important in handling IoT devices. Better design of MAC protocol is one of the ways to use energy efficiently. The important attribute of MAC Protocol is energy efficiency. MAC protocol is considered as a sub layer of the data link layer. It defines the rules to transmit the frame. If there are many nodes, the MAC protocol coordinates the channel access.

A popular MAC standard described by the Institute of Electrical and Electronics Engineers (IEEE) in 2003, and then revised in 2006. IEEE 802.15.4 defines two operation modes, i.e. non-
beacon-enabled mode and beacon enabled mode. The former is always awake to receive a frame. The latter describes super frames where nodes are only awake during a small portion of a super frame. This causes increase in energy consumption and throughput.

The basic idea of duty cycle protocol is to reduce the unnecessary activity by placing the node in the sleep state. This is represented as a periodic wake-up scheme. A node wakes up periodically to transmit or receive packets. If there is no activity, the node returns to the sleep state.

Duty cycle is measured as the ratio of the listening period length to the wake-up period length. There are various low duty cycle protocols which are classified as synchronous and asynchronous. The concept of synchronous is related with data exchanges. There are two basic concepts in asynchronous namely, transmitter-initiated and receiver-initiated. In the former approach, a node frequently sends request packets until reaches the destination. In the latter approach, a node sends packets to inform the neighbouring nodes about the willingness to receive packets.

To achieve low power operation, several MAC protocols are proposed. The types of protocols for IoT are MQTT, XMPP, DDS and AMQP. MQTT is a protocol for collecting device data and communicating it to servers. XMMP is called “Jabber” i.e. extensible messaging and presence protocol for connecting devices to people. It uses XML text format. Data Distribution Service (DDS) is a fast bus for integrating intelligent machines. This targets devices that directly use device data. Advanced Message Queuing Protocol (AMQP) is a queuing system designed to connect server to each other. Thus, Energy could be efficiently handled by proper design of MAC protocol

6.4 Security Management

Energy is an important factor to consider security measures for nodes. But, security systems are not designed for resource-restricted devices. One of the challenges is to make encryption algorithms faster and less energy consuming. The existing techniques are supported for powerful equipment. It is important to limit the energy consumption and thereby extend the battery life. Security measures have significant impact on its energy consumption in order to perform the encryption and decryption functions.

Security requirements involve in each layer of IoT. In perceptual layer, authentication is necessary to prevent illegal node access. Then, to protect the confidentiality of information, data encryption is necessary. If stronger are the safety measures, it consumes more resources.

In the network layer, it is difficult to apply the existing communication security mechanisms which consume more energy. Confidentiality and integrity are important in this layer.

There are two aspects in application layer i.e., authentication and key agreement across the heterogeneous network. The systems are not designed for resource-restricted devices. Therefore, lightweight cryptographic algorithms are needed to be implemented in this layer.

6.5 Topology Management

The role of topology control is to reduce the node power consumption. It is the way to extend network lifetime. The types are as follows:

- **Graph-Based Topology control**
  This is done locally if information about distances between sensors and their relative position is available. Several graphs exit with different properties.
- **Relative neighbourhood Graph**
  This is a straight line graph that connects two points. The triangulation of a point is a maximal of non intersecting line segments with vertices in the point.

- **Gabriel Graph**
  Gabriel and Sokal have introduced this graph. Every sensor in the network knows its neighbours and their locations. Each sensor determines its logical neighbour by computing the closed discs of diameters.

- **Localized Minimum Spanning Tree**
  It computes a power reduced network topology by constructing a minimum spanning tree over the network in a fully distributed manner. This approach is less energy-consuming than the original network.

### 6.6 Routing

Routing is the act of transferring information across network from a source to a destination. It occurs in network layer. Routing is making the decision which routes to use. Routing can be divided into flat-based routing, hierarchical-based routing and location-based routing.

All nodes are assigned equal role or functionality in flat-based routing. In hierarchical-based routing, nodes will play different roles in the network. Nodes’ positions are exploited to route data in location based routing. These protocols can also be classified into multi-path based, query-based, negotiation based, QoS-based and coherent-based routing.

- **Protocol Characteristics**
  The characteristic of routing protocols can be classified into three major categories such as proactive, reactive and hybrid protocols. A proactive protocols gathers routing information proactively, attempting to have an overview of the entire network’s topology at all times. A reactive protocol searches for routes on-demand. Only when a transmission starts, the route discovery process is triggered. Hybrid is the combination of both.

  Packet forwarding may be either hop by hop or through source routing. With the former, each router stores a small part of each route. With the latter, the entire path of a route is utilized for data transfer. This has the benefit of memory efficiency. It increases header size and traffic volumes. A protocol employing multipath routing seeks alternative paths towards every destination. With the probabilistic routing, routing decisions are calculated based on probabilistic values.

  Energy efficiency could be introduced to the existing protocols with the help of suitable metrics. The most common metric is Hop Count. The route using fewest hops is chosen. A metric which takes energy level on either the node or network level may influence the routing decisions of a protocol in a way which preserves energy resources [12].

### VII. CONCLUSION

The emerging domain of IoT has been attracting the researchers now. In this article, we have studied the issues like idle listening, collision, overhearing, reduction of protocol overhead and traffic fluctuation. We have also proposed the ways for energy conservation such as node activity management, data aggregation, transmission process, MAC protocol, security management, topology management and routing. There is very little research done in improving energy efficiency in energy constrained devices. The future research work will focus on detailed study of Energy Efficiency in routing.
REFERENCES