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A Novel Networking & IoT Platform for Wireless Sensor Networks

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ABSTRACT: Wireless Sensor Networks (WSNs) are being used on a large scale to monitor real-time environmental status. WSNs face various design issues concerning energy, memory, and cost constraints, which has attracted a lot of research work in recent times. However, an often overlooked aspect of WSN is a robust IoT platform to support the operations of a WSN. An IoT platform for WSN creates the opportunity to gather data reliably from the sensor nodes, effectively monitor an activity, provide visualization of collected data for the general public, and to administer the network effectively. This paper presents an IoT platform for wide-area and heterogeneous sensing applications. The development of this platform will prove to be essential in bringing networking capabilities in low-cost microcontrollers and in bringing development times down for IoT deployments.

KEYWORDS: Wireless Sensor Networks(WSNs), Internet of Things (IoT), Internet

I. INTRODUCTION

Wireless Sensor Networks (WSNs) is an emerging field of research which is closely related to the domain of Internet of Things (IoT). WSNs are a spatially dispersed network of battery-powered sensor nodes that monitor a particular physical quantity in the environment. This is achieved through multi-hop transmission of sensed data from the source device to a base station. These devices consist of a radio transceiver, microcontroller unit, and sensors, and are also commonly referred to as 'motes'. WSNs can be used for processing, analysis, storage, and mining of the data.The research on WSN is commonly focused on issues like energy efficiency, data aggregation, power-saving, efficient routing, sleep schedule, and communication protocols. Energy consumption is an important consideration because the motes are battery-powered and charge over renewable sources of energy like solar energy. Sleep scheduling and efficient routing are ways in which energy consumption can be kept at a minimum. Apart from energy consumption, the issue with low cost embedded systems is the lack of memory space in terms of program memory as well as RAM. Due to memory constraints, all mote functionality and communication protocol stack should have a small code footprint.

Internet of Things (IoT) is the networking of physical objects that contain electronics embedded within their architecture to communicate and sense interactions amongst each other or concerning the external environment. The object can be a heart monitoring device, a remote, or an automobile with built-in sensors. In the upcoming years, IoT-based technology will offer advanced levels of services and practically change the way people lead their daily lives. Advancements in medicine, power, gene therapies, agriculture, smart cities, and smart homes are just a very few of the categorical examples where IoT is strongly established. The integration of wireless sensor networks in IoT brings new technical challenges, including complex event processing, large scale systems, real-time data processing, and privacy. Incoming data from sensor networks can trigger certain events and services in real-time. Applications can use this data to determine the context, location, and environment of the data source and decide which other services can be relevant to the current data set to make the right decisions. Data privacy is of critical importance. When data leaves the sensor network and arrives at the cloud, adversaries can try to gain access to it. Data collected by the sensor network is often sensitive, and great attention needs to be paid to security and data protection.

An often overlooked aspect of WSN is a robust IoT platform to support the operations of a WSN. An IoT platform is a multi-layer technology that enables provisioning, maintenance, and automation of motes. An IoT platform is responsible for connecting the WSN to the internet, uploading data received by all motes to the cloud/database, maintaining a record of all necessary activities of the network, and providing data visualization and network administration tools to network administrators. IoT platforms enable administrators to realize IoT projects and build IoT solutions faster, cheaper, and better. IoT platforms are the support software that connects everything in an IoT system. An IoT platform facilitates communication, data flow, device management, and the functionality of applications. With more IoT devices or assets, data, related technologies, network or connectivity solutions, architectural and infrastructural evolutions, and stronger requirements to connect and leverage it all in a purpose-driven, efficient, interoperable, and secure way. IoT platforms have become the backbone of professional IoT deployments.

The distinction between WSN and the internet is an important aspect of WSN-based IoT Platforms since the nature of the two networks is very different. The WSN nodes operate at custom-built communication protocols rather than the traditional TCP/IP protocols. Thus, for data to be uploaded on the server, a protocol conversion interface is needed between the two networks. In this paper, we present a survey of literature on various IoT platforms and communication protocols required for WSNs (Section II) and provide a brief description of the proposed IoT platform (Section III). Finally, we provide a brief discussion of the results obtained through the IoT platform (Section IV).

II. RELATED WORK

A lot of work has been conducted in the area of IoT applications, using WSNs. The common theme of all related work is that the IoT platform provides reliable connectivity between sensors on the field and database on the internet. The literature review gives an overview of the different types of Medium Access Control protocols, Routing protocols, and Transport protocols that are used in any WSNs. Based on the information, a robust protocol stack is to be developed.

Wireless Sensor Networks (WSNs) have generated increasing interest from industrial and research perspectives. A WSN can be generally described as a network of nodes that comparatively sense and may control the environment. On one end, WSNs enable new applications, and thus new possible markets, on the other hand, the design is affected by several constraints that call for new paradigms. The activity of sensing, processing, and communication under a limited amount of energy, ignites a cross-layer design approach typically requiring the joint consideration of distributed signal or data processing, medium access control, and communication protocols.

In [1], an IoT platform, SDIoT (Software-defined IoT) has been proposed. SD-IoT provides reliable connectivity between sensors on the field and database on the internet. Once raw data is collected from each device in the network, it is sent to the gateway. Different hoping techniques have been used to relay the data towards the sink. IEEE 802.15.4e time-slotted channel hopping protocol has been used at the MAC layer. The gateway then buffers the raw data in a queue and sends them one by one to the processing sub-unit. The processing sub-unit then processes the data according to the configuration stored in the database for each sensor.

In [2], authors present a survey on IoT platforms, discussing their architectures and fundamentals of IoT building elements and communication protocols between them. The paper aims to help the reader choose a suitable and adequate IoT platform for their demands in the huge number and variety of platforms available. The survey provides a comprehensive view of the components and features of the state-of-the-art IoT platforms. The platforms are classified in many aspects such as device management, integration, security, protocols for data collection, types of analytics, support for visualizations.

Disseminating information in sensor networks with tight energy restraints is still an open problem and there is a need for routing protocols specifically low energy and asymmetric communication with realistic assumptions about the frequency of topology changes and the number of nodes in the network. Routing protocols have been proposed, but most of them need to be improved because they assume mostly static topologies and a smaller number of nodes (a couple of hundreds instead of thousands).In literature [3], [4], [5], there are three broad categories of WSN routing protocols: Data-centric, Hierarchical, and Geographic (Location-based). Apart from these, Opportunistic routing is an emerging category of routing protocols for WSNs. Routing Protocols used in Mobile Adhoc Networks (MANETs) can also be useful in WSNs with mobile nodes. Data-centric routing focuses on the sensed data and is not interested in knowing the origin of the sensed data from individual nodes. Thus, nodes are not uniquely identified in data-centric routing. In Hierarchical Routing, nodes form groups called as Clusters and elect a cluster head among themselves. The cluster head is responsible for transmitting data of all nodes in the cluster towards the sink node. In Geographic (Location-based) Routing Protocols, nodes are identified by the location/area they lie in, instead of having unique identification for each node. Any node lying in a geographic area is accepted as a recipient of information being sent to that area. In Opportunistic Routing, the source node broadcasts the packet to all forwarding nodes, which then collaborate to relay the packet. MANET routing protocols are designed for mobile nodes with frequently changing topologies.

There are four broad categories of MAC protocols: Schedule or Reservation-based, Contention-based, Channel-polling based, and Hybrid [6], [7], [8] in literature for WSNs. In contention-based channel access, each node competes with its neighbours for access to the channel. In scheduling/reservation-based MAC, collision-free links are assigned between neighbouring nodes. Channel-polling refers to scanning the wireless channel periodically to detect activity in the wireless medium. Hybrid MAC protocols attempt to combine the strengths of two different types of MAC schemes. However, hybrid protocols are susceptible to complexity and scalability issues.

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The goal of the project is to develop an energy-efficient and reliable, cross-layer design approach for the platform. To achieve this goal, a reliable transport protocol for wireless sensor networks needs to be implemented. There has been inadequate work done on the designing of efficient transport protocols, so new transport schemes need to be introduced that focus on energy-efficiency and take advantage of the collaborating nature of sensor networks.

III. PROPOSED SYSTEM

Any IoT platform for WSN has four important components:Gateway, Communication Protocol Stack, Data Visualization Tools, and Network Management Tools. The IoT platform bridges the gap between WSN and the Internet through the Gateway interface. The role of the gateway is to receive application data from WSN nodes and upload it to the database through HTTP requests.Data visualization tools are essential for an IoT platform to provide an intuitive visualization of the data collected by sensor nodes at various locations. The proposed platform provides network administrators with the option of showing data to the general public through an intuitive and easy to understand heat map representation. Network management tools are essential for network administrators to monitor, configure, and effectively manage all the network entities like WSN nodes, a sink node, gateway, applications, visualization tools, etc.

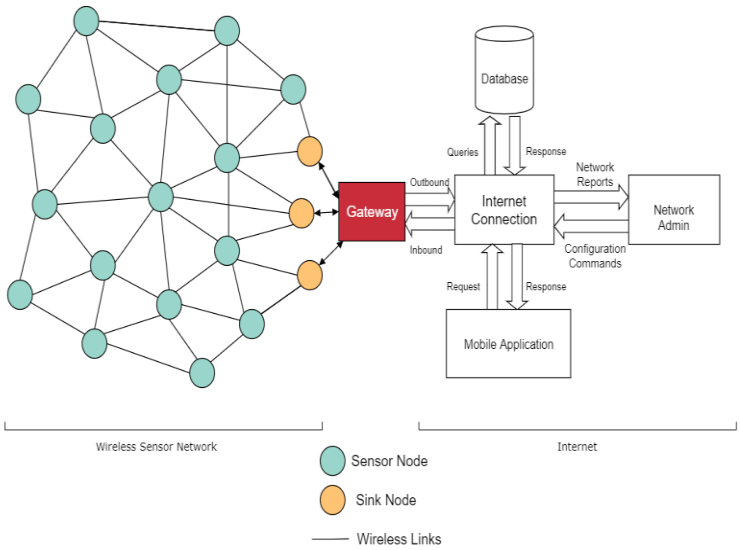

Fig. 1. Block Diagram of proposed IoT Platform and its interface with WSN

A. Gateway Device:

The Gateway device is a much more powerful computer than the sensor nodes. It receives application data from the sink nodes and uploads it to the server. Thus, the gateway operates at the application layer protocol of the WSN as well as of the Internet (HTTP). The gateway does not operate at the lower layers of the protocol stack. The lower layers are taken care of by the sink nodes. Also, the sink nodes take care of all networking and transport functions and deliver data from nodes to the gateway and vice-versa.

To connect the WSN to the internet and log all data generated by motes to a database on cloud/server, a gateway device is needed to receive data in the format specified by the application layer of WSN and convert it to an HTTP request to upload it over the internet. The gateway device requires a mote connected to its port so that the gateway can communicate with other motes in the network. This mote has only a radio interface and microcontroller unit, but no sensors, and is commonly referred to as 'sink node'. This sink node acts as an interface or a bridge between the gateway and the WSN. Apart from uploading data received from sink nodes, the Gateway device is responsible for sending management commands to the network, pushing Over-The-Air (OTA) updates to the network and other management services. Also, the Gateway device can query the nodes to know their status.

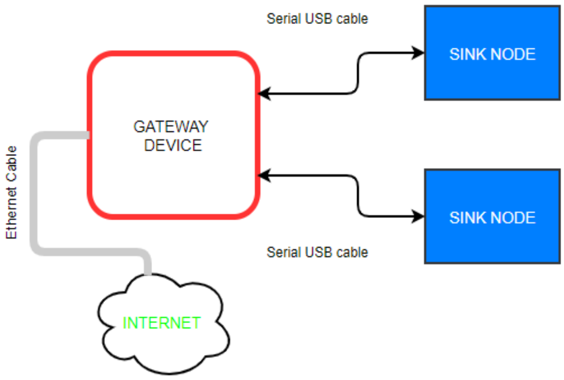

Fig. 2. Block Diagram of Gateway-Sink Node Interface

B. Communication Protocol Stack:

The communication protocol stack is responsible for setting up the network topology and transporting data. The network should be self-organizing as the nature of WSNs is ad-hoc. The energy and Resource-constrained nature of WSN requires a protocol stack to provide the desired Quality-of-Service (QoS) with certain trade-offs. The proposed solution implements a protocol stack with cross-layer implementation.

At the transport layer, two different levels of QoS have been provided. For periodically generated traffic which is loss-tolerant, no reliability measures have been provided. The reliable reception of this data has to be taken at the application layer. Thus, the application in question decides the type of QoS to be provided for the given data. For OTA updates, the PSFQ [9] (Pump Slowly Fetch Quickly) Protocol is most suitable at the transport layer. The merit of PSFQ is that since the source is pumping/transmitting segments at a slow rate, the segments arrive in order at the receiver. This eliminates the need for reordering the received segments and lengthy transport buffers. Thus, PSFQ is lightweight in terms of memory requirement and computation complexity.

The Network Layer and the Medium Access Control (MAC) Layer in the proposed protocol stack, aims at providing a fair and minimum-contention medium access to all nodes. MAC protocol plays an important role in energy consumption for wireless sensor networks. The MAC protocol used is CSMA/CA without RTS/CTS mechanism, but with a precautionary backoff. The precautionary backoff period is unique for each node and helps in avoiding collisions. In the traditional MAC protocol using CSMA/CA with RTS/CTS mechanism, control packets are exchanged for avoiding the collision of larger packets, and the collision of smaller control packets is permitted. However, in typical WSN applications, especially with low-cost and low computational-resources microcontrollers and processors, the packet size is always small. This makes the RTS/CTS mechanism unsuitable for WSNs. Also, the overhead involved in the RTS/CTS mechanism becomes significant in WSNs for avoiding collisions. The routing protocol used is the Sink-aware Routing Protocol (SaRP), which takes advantage of the fact that in WSNs, the goal of every sensor node is to report its data to one of the sink nodes in the network, reducing the need to build routing tables for multiple source-destination pairs. At the Physical and the Data Link Layer, any existing protocol suite or radio unit can be used. However, since protocol stack design is cross-layer, the information from physical and data link layers are vital for the efficient functioning of the entire protocol stack.

C. Data Visualization:

The proposed IoT platform provides a tool for intuitively visualizing the data collected by the WSN. The interpolation of discrete values is performed to generate a heatmap visualization for general purpose viewing. The interpolation technique applied is Inverse Distance Weighting (IDW). IDW calculates the weighted average of points with known values and assigns a higher weight to the nodes closer to the point.

The equation for performing IDW as per Shepard's Method [10] is as follows:

$$u(\mathbf{x}) = \begin{cases} \dfrac{\sum_{i=1}^{N} w_i(\mathbf{x}) u_i}{\sum_{i=1}^{N} w_i(\mathbf{x})}, & \text{if } d(\mathbf{x}, \mathbf{x}_i) \neq 0 \text{ for all } i, \\ u_i, & \text{if } d(\mathbf{x}, \mathbf{x}_i) = 0 \text{ for some } i, \end{cases}$$

Where,

$$w_i(\mathbf{x}) = \frac{1}{d(\mathbf{x}, \mathbf{x}_i)^p}$$

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Here, u_i is the known value at a node i. w_i is the weight assigned to the particular node. $d(x, x_i)$ is the distance between the point and the node. N is the total number of surrounding nodes, p is a real positive number called the power parameter. The value of p determines the influence of proximity on the weights. Higher values of p assign greater influence to values closest to the point. The network administrator needs to decide the value of parameter p according to the application of WSN.

To include use cases like Air pollution monitoring, which rely on wind speed and direction, the IDW has been modified to include the effects of wind speed and direction. The nodes that lie in the direction of wind towards a point, have been assigned a higher weight. The degree to which weight is added to nodes lying in the direction of the wind depends on the wind speed.

D. Network Management System:

A network management system designed for WSNs (WSNMS) provides a set of management functions that integrates configuration, operation, administration, and maintenance of all elements and services of a sensor network. Since management messages consume the resources of WSN, care has been taken to keep such messages at a minimum. The proposed system keeps track of minimum yet critical aspects of WSN like topology, connectivity, battery levels, sensing range, and communication range of the nodes. To keep management overhead low, each node reports information only about its neighborhood on initialization. After initialization, the nodes report to the gateway only if there are any changes in the topology. Apart from that, each node also reports its battery voltage level with the sensed data itself, to further reduce management overhead.

IV. RESULTS AND DISCUSSIONS

The proposed IoT platform is robust, provides seamless integration of WSN with the internet, and provides data visualization and network management tools for network administrators. Fig. 3 and Fig. 4 show the resulting data visualization tool using heatmap representation. In Fig. 4, the influence of wind is seen in regions where node density is low. The proximity of a node is a much important deciding factor in the value at a point than the effect of wind. Thus, as seen in Fig. 4, the influence of wind is observed only in a region that is not in close proximity to other nodes. This is a desirable result, since the sensed value at the points on which the nodes lie, is physically sensed using sensors and not estimated through interpolation. This shows that if sensing density is high, more accurate results can be generated.

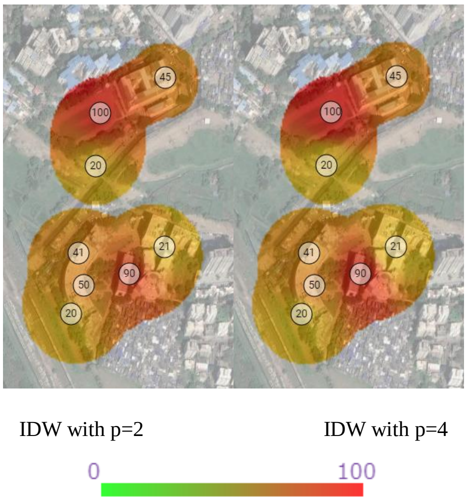

Fig. 3. Comparison of Heat Map with different values of the power parameter

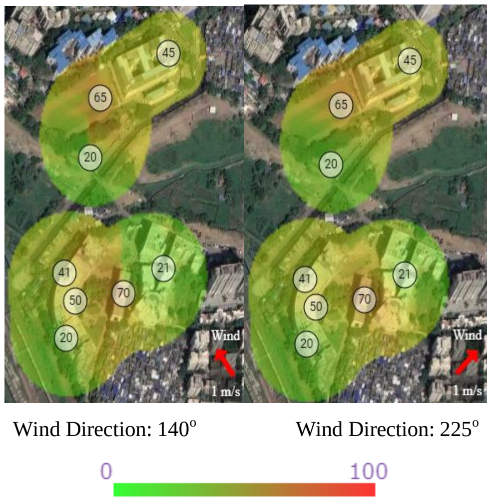

Fig. 4. Comparison of Heat Map with different wind directions

The Wireless Sensor Network Management System (WSNMS) has been developed for network administrators to manage, configure, monitor, and troubleshoot the network remotely. The WSNMS is lightweight and provides minimum but critical functionality to reduce management overhead in the network. Functions like monitoring of network topology, sensing range and communication range estimation, and sensed data analytics have been successfully implemented under this system. In Fig. 5, the administrator uses these topology map results to detect faults in the network like node failure or re-evaluate the placement of sensor nodes. In Fig. 6, the administrator provides inputs for estimating the sensing coverage area based on the sensing range of the sensors and area to be sensed. The communication coverage map helps the administrator to adjust the range based on the transceiver and transmit power level used. The administrator uses the results shown in Fig. 6 and Fig. 7 to decide the deployment of new nodesto expand the network. The new node should expand the sensing coverage to a specific region, and should also be in the communication range of at least some nodes in the network. Fig. 8 shows the links and estimated isotropic communication range of an individual node. The administrator uses these results to retrieve information about individual nodes in the network.

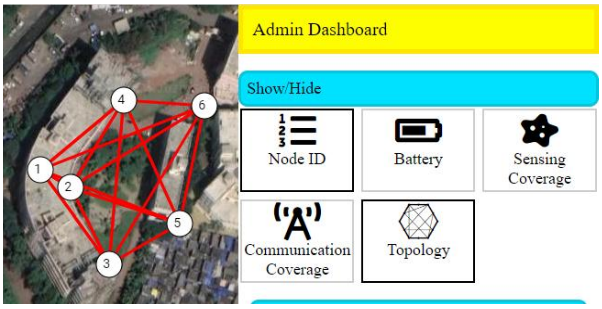

Fig. 5. Admin Dashboard Topology Map

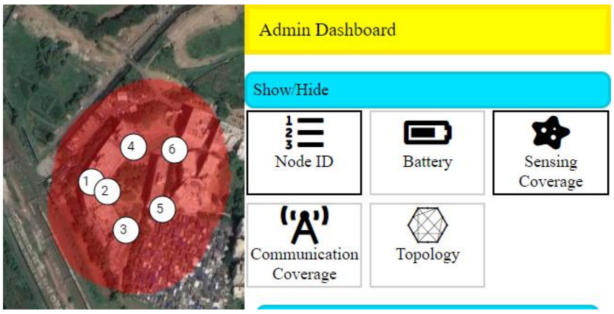

Fig. 6. Admin Dashboard Sensing Coverage Map

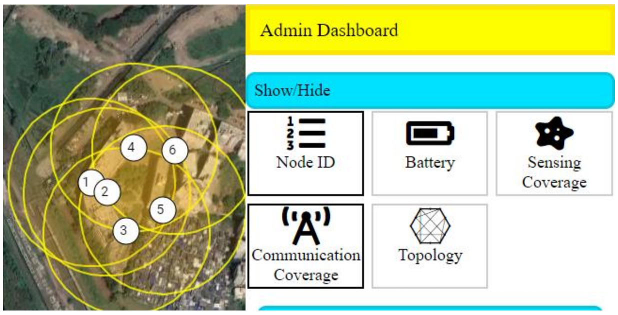

Fig. 7. Admin Dashboard Communication Coverage Map

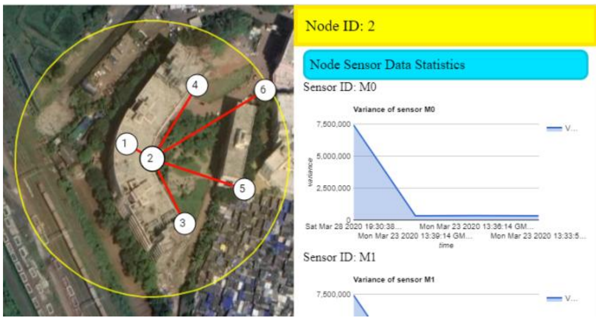

Fig. 8. Information of Individual Node

V. CONCLUSION

In this paper, we presented an IoT Platform for WSNs with low-cost, low-memory, low computational power, and energy-constrained motes. Our work involved the development of communication protocol stack and gateway device for networking platform and database scripting, data visualization tools with heatmap representation, and network management system for the IoT platform.The development of this platform will prove to be essential in bringing networking capabilities in low-cost microcontrollers and in bringing development times down for IoT deployments so that the administrator can focus on building applications instead of the underlying hardware, software, and any other technologies.

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