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APPLICATIONS OF INTERMITTENTLY CONNECTED DELAY TOLERANT WIRELESS SENSOR NETWORKS (ICDT-WSNS) – A SURVEY

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ABSTRACT

Studies of Intermittently connected delay tolerant wireless sensor networks (ICDT-WSNs) are a new field gaining more popularity for various new applications. These networks are an integration of both wireless sensor networks (WSNs) and delay tolerant networks (DTNs). ICDT-WSNs like the WSN have limited resources and like DTNs have intermittent connections. Traditional wireless sensor networks are appropriate for applications that have an end-to-end connection between the source and destination nodes, but they are not suitable for some applications that have not end-to-end connections between source and destination nodes and have intermittently connected. ICDT-WSNs designed for these types of applications. By recognizing the characteristics of these networks, different applications can offer to them. Surveying of these applications can be led to identify the core needs of ICDT-WSNs and propose efficient protocols for ICDT-WSNs. This paper summarizes and compares some applications of ICDT-WSNs and characteristics and requirements.

Keywords: Wireless Sensor Networks, Intermittently Connected, Delay Tolerant networks.

1. INTRODUCTION

Delay-tolerant networks (DTNs) are an approach that attempts to find solutions in heterogeneous networks that may not have continuous connectivity. This type of network can be an example of mobile or space-planned networks [1-3]. In DTNs there is not full connectivity on all the network, and end-to-end transmitting is difficult or impossible to establish, so DTNs use a "store and forward" approach for data transmission.

Wireless sensor networks (WSNs) consists of many small sensor nodes that distributed in considered environment for gathering information for transmitting to Sink node for processing; these nodes had one or multiple sensors for sensing environmental data and communicate each other by wireless communication [4, 5].

Intermittently connected delay tolerant wireless sensor networks (ICDT-WSNs) [6, 7] are an integration of both wireless sensor networks (WSNs) and delay tolerant networks (DTNs). ICDT-WSNs like the WSN have limited resources and like DTNs have intermittent connections. Applications of these networks are increases in many cases such as wildlife monitoring, different underwater uses, surveillance systems, etc.

The rest of this paper organized as follows: The overview of ICDT-WSNs and the challenges and characteristics of these networks presented in Section II. Section III describes some applications of ICDT-WSNs and its requirements. Section IV compare applications of ICDT-WSNs briefly. Finally, Section V concludes this paper.

2. MATERIAL AND METHOD

2.1. Intermittently Connected Delay Tolerant Wireless Sensor Networks (ICDT-WSNs)

Intermittently connected delay tolerant wireless sensor networks (ICDT-WSNs) are a new branch of both WSNs and DTNs. Applications of ICDT-WSNs increased in recent years, so the study of these networks is necessary. ICDT-WSNs have some characteristics such as low energy, low computation capability, low storage space, low bandwidth, small communication range, low duty-cycle, long delay on packet delivery and intermittent connection. The intermittent connection can occur due to energy depletion, environmental conditions (harsh environments, obstructions block, etc.), the sparseness of network, wireless radio broadcast limitations, attacks, noises and node mobility [2, 3, 6]. ICDT-WSNs are mission based, that means all nodes in an ICDT-WSNs cooperate to carry out the common mission of the network, that requires that they should provide a high rate of data delivery with acceptable latency. ICDT-WSNs support local communication, such that nodes collect information from considered area and typically exchange this information with the nodes in their neighborhood. Routing decisions in ICDT-WSNs are made locally without requiring all information of all network, and like DTNS is used store-carry-forward mechanism for routing. [8-10]. Using this mechanism lead to change in nodes structure of traditional sensor nodes and adding storage to sensor node as shown in Fig-1.

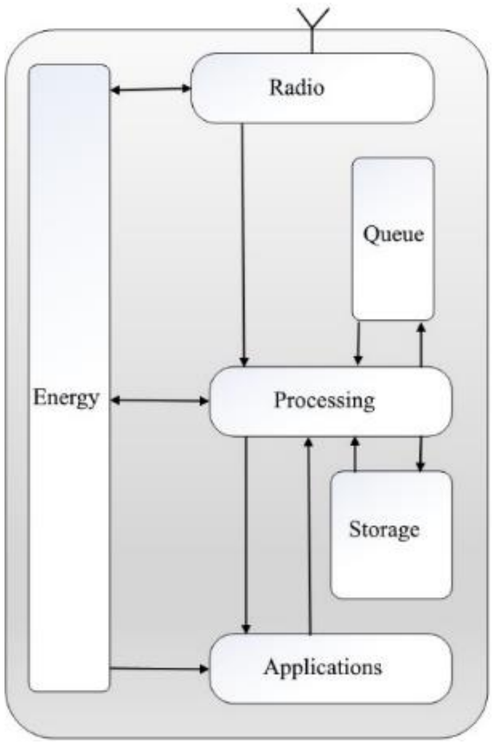

Fig.1. ICDT-WSNs node structure [7]

The intermittent connection in ICT-WSNs leads to needs a Bundle layer [1] above transport layer like DTNs, as shown in Fig-2.

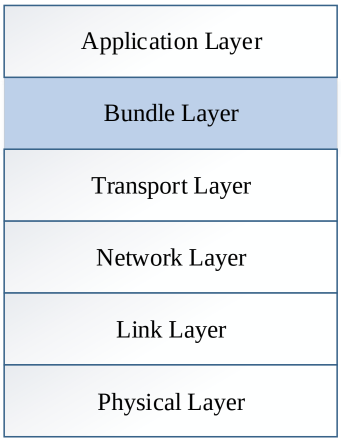

Fig.2. ICDT-WSNs Layered Architecture

The store-carry-forward mechanism done by using Bundle protocol. Each node collects data in a Bundle and store in the storage of itself. The nodes carry the stored data along with itself, then in an appropriate time transmit this data to a suitable neighbor node, this store-carry-forward mechanism continued until data reach to Sink node. The ICDT-WSN communication media is a wireless channel whose nature is broadcast. This feature complicates data access and transmission through shared media. In addition, constraints on node energy, storage and computability, asymmetric links, dynamic topology, and large number of nodes in the network make Media Access Control (MAC) protocols for WSN different from traditional network protocols. So in this type of network, asynchronous mac layer protocols like X_MAC, B_MAC and etc, are used. In conventional ICDT-WSNs, protocol zigbee (IEEE 802.15.4) is usually used, which is used bandwidths of 868-868.8 MHz, the 902-928 MHz or the 2.400-2.4835 GHz Industrial Scientific and Medical (ISM) bands [11]. Because communication in underwater networks is susceptible to noise, therefore, acoustic is used instead of wireless, and the bandwidth used in such networks are very long (less than 1KHz), long (between 2 - 5 KHz), medium (10 KHz), short (between 20 - 50 KHz) and very short (more than 100 KHz) [12].

2.2. Characteristic of ICDT-WSNs

ICDT-WSNs have some characteristics and restrictions [1, 5-7], which described as following briefly;

- *Intermittently connected:* Due to the intermittent connection, the end-to-end path is not existing always. Therefore, traditional protocols are not appropriate for ICDT-WSNs.
- *Asymmetric data rate:* Wireless links in ICDT-WSNs have asymmetric data rate, so traditional flow control protocols like TCP is not suitable for these networks.
- *High error rate:* The error rate in ICDT-WSNs is very high, so due to error recovery and retransmission, traffic is a lot.
- *Random mobility model:* In most of this type networks mobility model of nodes is not exactly predictable.
- *Limited computation capability:* As mentioned, nodes of ICDT-WSNs are small device and have limited resource (such as computation capability, storage, and energy) therefore cannot process complex protocols and cannot handle a large amount of traffics.
- Nodes transmission range is small and transmitting data from source to destination carried out using hop-to-hop transmission mechanism.

2.3. Challenges in ICDT-WSNs

Many challenges in ICDT-WSNs are not in traditional networks that some of [1, 5-7, 13, 14] them described as follow;

- *Connection Scheduling:* One of the ICDT-WSNs challenges is link scheduling, that related to environmental conditions of the network. Networks environmental conditions are different from predictability aspect, in some applications, intermittent connections of the network are predictable and, in some others, are not predictable exactly.

- *Routing:* Because of intermittent connection, routing is a major problem in these networks, such that transmitting data packets to destinations is done using the store-carry-forward mechanism to overcome the intermittent connectivity.
- *Storage management:* Due to the long delay in ICDT-WSNs, packets must store in the storage. In the others hand the storage capacity of nodes in ICDT-WSNs are small so maximize the utility of storage is significant.
- *Energy management:* Nodes in ICDT-WSNs are resource restricted. The power consumption of these nodes influenced by protocols of all layers, so designed protocols for these networks must be energy efficiency.
- *Error control:* Loss recovery for packet loss happens during transmission due to intermittent connection and due to the overflow of storage or queue, so must design of efficient error control mechanism for ICDT-WSNs is so essential.
- *Duty cycle:* Due to the mobility of nodes in ICDT-WSNs, synchronization of nodes is very difficult or impossible. Therefore, asynchronous duty cycle mechanisms must design for these networks.
- *Medium access control:* Topology change, and intermittent connections are two critical characteristics of ICDT-WSNs, Because of this, traditional mac protocols are not appropriate for these networks. MAC protocols designed for these networks must be asynchronous and proper for topology change and intermittent connection.

3. APPLICATIONS OF ICDT-WSNS

As previously mentioned, applications of ICDT-WSNs increased recently, by appearing new applications, new challenges appeared also. In this section, some applications of ICDT-WSNs described briefly.

3.1. Wildlife lives monitoring network (ZebraNet Project)

ZebraNet is a network designed to monitor the lives of wildlife. On this network, sensor nodes attached to the neck of the animals (Zebras). The nodes in this network are equipped with a global positioning system (GPS) [17] to record the exact location of the examining animals and their migration. Also, the nodes are equipped with temperature and humidity sensors and other sensors to monitor the vital signs of the animals under monitoring. There is no fixed point in the network to collect data from the mobile sensor nodes, and researchers periodically go to animals living area to collect recorded data. Therefore, in this network, in addition to the mobility of the nodes, the Sink nodes are mobile also. The sink nodes may not be available for a long time (several days) (in other words, they do not enter the area to collect data). In this network, designed nodes should have low weight, which it severely limits the design of the nodes and the available energy of nodes. Despite the few numbers of sensor nodes in this area, it is not possible links available always [15,16].

3.2. Wild animal’s environment monitoring (Wild-Cense)

Like ZebraNet this project also is for monitoring wild animal’s environment. Sensor nodes attached to animals are collected data about environmental conditions (include location information using Global Positioning System (GPS), temperature, humidity, orientation, and light) of animals living area. When nodes come with in communication range of each other exchange collected data. And when nodes come to the communication range of Sink node transmit data to Sink node. In this application sensor nodes have mobility and carried with animals. There is no connection between nodes all of time and network is intermittently connected, so ICDT-WSNs is so convenient for this application [18].

3.3. Wild deer behaviour monitoring system (WildSense)

WildSense is a new and accurate system for monitoring the behavior of wild deer in the rough desert. This system combines the features of GPS and RF-radio sensors for creating low cost and low resources system. The system designed to build continuously track the location and behavior of wild deer in harsh environments for several months. WildSense consists of collar nodes and a delayed tolerant network for transmitting data between collar nodes. This system uses the DTN network protocol to exchange data between nodes. DTN is appropriate to overcome the disconnection between nodes in this system, which the nodes exchange their data when they are close together, and when the nodes are out of each other range store data for future exchanges. As a result, ICDT-WSNs ideally suited for the transfer of data between mobile animals that may only connect intermittently [19].

3.4. Applications in underwater communication

Over the past few years, underwater wireless sensor networks (UWSNs) have grown considerably. UWSNs used for environmental monitoring, seismic exploration, prevention of unexpected events, assistance to ships, tactical monitoring, and mine detection under the sea, in the oceans. Acoustic underwater communication has a long usage in military applications, compared to radio waves that do not work well due to the high attenuation in water, the acoustic has high performance in water, which has led this technology considered for underwater communications. Underwater Wireless Sensor nodes have mobility usually because of the flow of water, and these nodes due to using acoustic communications encountered with the high error rate, high transmission delay, and limited bandwidth. Compared to ground sensor nodes, underwater sensor nodes are usually slightly Larger, with more power consumption, harder charging, and more expensive. As a result, the implementation of underwater sensor nodes at the depths of the sea is high cost. Due to the mobility and sparsely implementation of UWSNs, these networks can become easily partitioned, so there may not be a continuous path between source and destination always. As a result, a UWSN can consider as an ICDT-WSN [20,21].

3.5. Underwater wireless sensor networks

This work is one of Underwater Wireless Sensor Networks (UWSNs), that use radio tagged whales as sensor nodes for collecting biological data from the environment and use seabirds as data collector (Sink node) node from sensor nodes. Sensor nodes that attached to whales sense data from the environment and transmit toward Sink node through other sensors. In this project Sink nodes also have mobility, and when other nodes come in the communication range of sink nodes can transmit their collected data to Sink nodes. As discussed before, the mobility of nodes in the network can be the cause of intermittent connection and lack of the end-to-end path, so ICDT-WSNs are most suitable for this application [22].

3.6. Sandstorm monitoring and warning system (Standstorm Forecast)

Sandstorms have a harmful effect on human health, natural environments and national economy in some area of the world, so the study of sandstorm monitoring and warning system is a critical issue. In this project, wireless sensor networks used for monitoring and warning purpose. After installing WSNs in the considered area, sensor nodes collect some data (such as atmospheric pressure, temperature, humidity, wind speed, and soil moisture status) from the area and transmit to the remote-control system for processing and warning purpose. In this system during sandstorms transmission range of sensor nodes are decrease and locations of nodes are changing so the connection between node can destroy and the end-to-end connection broken. Due to these ICDT-WSNs is the most proper for this application [23].

3.7. Coalmine structure surveillance monitoring system

One of the critical applications of the sensor networks is the monitoring of the coal mine environment. Monitoring the many environmental conditions such as gas, water, and dust, in underground tunnels with a length of about several kilometers and a width of about a few meters is critical to ensuring healthy working conditions in coal mines. Sample data should be collected at many different locations of a coal mine to obtain a complete monitoring of the underground tunnel. An accurate monitoring of the environment requires the use of many sensor devices. The unstable geological structure of coal mines leads to creating underground tunnels that are prone to structural change. Due to this change may be there is not exist the connection between sensor nodes continuously and the link between nodes is intermittently connected. Therefore, previous WSN monitoring system is not proper for this application and must use ICDT-WSNs [24].

3.8. Distributed state estimation (DSE) using multirobot systems

In this project, the problem of distributed state estimation (DSE) using multirobot systems is considered. Robots have limited communication capabilities and therefore, they can intermittently communicate only when close to each other. To reduce distance, robots move to communicate. They divided into small teams that can communicate in different locations to share information and update their ideas. This work proposes a new distributed plan that has two important goals. Providing communication programs that ensure intermittently connectivity, and second, sampling-based motion planning for robots in each team, with the aim of collecting optimal measurements and deciding where those robots will communicate [25].

4. COMPARISON OF APPLICATIONS

Different applications of ICDT-WSNs can be categorized based on network features such as mobility, transmission range, and storage capacity of nodes. They can also classify based on the node movement pattern and network partition frequency. In Table 1, some applications of ICDT-WSNs classified based on these fundamental characteristics.

Table 1. Comparison of Applications

	Multirobot Systems	Underwater network applications	ZebraNet	Wild-Cense	WildSense	Standstorm Forecast	Coalmine	Underwater
Mobile Sink		✓	✓	✓	✓			✓
Mobile Nodes	✓	✓	✓	✓	✓			✓
Random mobility model		✓	✓	✓	✓	✓	✓	✓
Predictable Mobility Model		✓	✓	✓	✓			✓
Limited Energy	✓	✓	✓	✓	✓	✓		✓
Limited Computing Capacity	✓	✓	✓	✓	✓	✓	✓	✓
Need to storage	✓	✓	✓	✓	✓	✓	✓	✓
Challenging Connectivity Media	✓	✓				✓	✓	✓
Long Delay	✓	✓	✓	✓	✓	✓	✓	✓
Requires carrier	✓	✓	✓	✓	✓			✓
Intermittently Connected	✓	✓	✓	✓	✓	✓	✓	✓
Network Partitioning	✓	✓	✓	✓	✓	✓	✓	✓

The comparison presented in Table 1 for ICDT-WSNs is dependent on the mobility pattern of the nodes, the delay limits, need for a carrier agent, and the difficulty of the environment. This comparison is the result of the discussion of ICDT-WSNs applications in the previous section. The important points in Table 1 includes;

Some applications have both mobile and fixed nodes. Many applications of ICDT-WSNs have this situation. In this case, different platforms work together under one algorithm. Similarly, in the table, some applications have any predictable and random mobility model. For example, this is quite observable in wildlife, that in the normal situation is predictable and when there may not occur natural events for many reasons is random. In Table 1, the "Challenging Connectivity Media" feature refers to situations where wireless signals released from sensor nodes attenuated or deflected due to environmental characteristics. These environmental features can include water, steam, volcanic materials, and industrial liquids. Energy consumption is a very critical parameter in many of applications, so this parameter must consider in designing of protocols for ICDT-WSNs.

5. CONCLUSION

In this paper, investigated the various applications of ICDT-WSNs. As discussed before, there are different applications for ICDT-WSNs, these applications are common in features such as long delay, network partitioning, and intermittent connections because of topological constraints, mobility, harsh environment, energy constrained, etc. The study of the applications of ICDT-WSNs is important because the study of the various characteristics of these applications can identify the requirements for applications of ICDT-WSNs. And these requirements can be used as a criterion for designing the algorithms for ICDT-WSNs, including routing algorithms and scheduling. As a result, investigating applications and them characteristics can help researchers to design more efficient algorithms.

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