DETN: delay-efficient tolerant network for Internet of Planet

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Abstract—The explosion of the internet has resulted in various emerging technologies, as for example the Internet of Things (IoT). IoT is an intelligent technology and service connecting objects in the Internet. IoT facilitates the exchange of information between people and devices that communicate with each other. Beyond IoT, we are now studying a new paradigm called Internet of Planets (IoP), in which planets in a solar system communicate with each other using the Internet. This paper presents our research in the internet communications between planets, detailing benefits, limitations and directions for future work. We propose a time (delay) information-based Delay Efficient Tolerant Networking (DETN) routing scheme for efficient data transmission among mobile nodes. The results of the proposed DTN routing algorithm using NS-3 simulation tools indicate satisfactory levels of routing performance in comparison with existing DTN algorithms.

Index Terms— **IOP, DTN, Delay Tolerant Networking, Internet of Planet, Sensor network.**

I. INTRODUCTION

INTERNET originated from ARPANET [1], a project built by the US Department of Defense in the 1960s for military purposes, which due to technologies available at the time was characterized by low data transmission rates. Since then, data transmission rate has become faster and more stable, due to Transmission Control Protocol/Internet Protocol (TCP/IP). What initially started as small networks expanding and connecting with each other, has sprouted becoming an indispensable part of the modern world – as a collection of huge computer networks around the world.

The Internet has the following important characteristics. 1) The Internet provides two-way communication between subjects who can participate simultaneously. 2) Network nodes can send and receive messages at any time, provided there is a connection to the network without time limitation. 3) In the early Internet, communication was possible only in text format, but now it can communicate in numerous formats including image, voice, or video. 4) The Internet provides anonymity regardless of one's job, social status, position, race, age, etc. The Internet system consists of a very large number of server and client machines interconnected using various transmission media.

A recent development of the existing Internet system is the IoT [2, 3], in which sensor-embedded devices communicate with various smart objects, often via wireless communication. Anything connected to the Internet requires a unique IP for identity and can incorporate sensors to acquire data from the outside environment. IoT is an intelligent technology in which connected objects exchange and analyze data, provide the learned information to users, or remotely control other devices. The IoT has expanded to include various embedded systems such as household appliances, mobile equipment, and wearable devices. According to Gartner [4], the estimated number of objects using IoT was over 900 million in 2009, but this number is predicted to rise above 26 billion by 2020.

Internet of Planet (IoP) is the first concept we introduce and defines interplanetary communication. IoP is also based on the Internet and is a concept for data communication in a very large space such as outer space and Galaxy. There are many technical challenges in designing IoP routing protocols such as high latency, limited resources, frequent disconnections, and predictable or opportunistic connections [5]. In several research projects, the performance of IoPs in terms of delay, overhead, throughput buffer size and number of nodes has been investigated.

Currently, space communication relies primarily on radio waves [6, 7]. This method has many advantages, although maintaining signal strength over long distances is its fatal weakness. If a network node is located close to the Earth (like a space station or the Moon), then there is no problem. However, when the distance is bigger the signal is weakened and the transmission speed is greatly reduced. For instance, in the case of New Horizons, which left for the exploration of Pluto, the speed of the installed modem was 32 kilobits per second (Kb) as it passed by Jupiter, but this fell to just 1 Kb per second as it reached close to Pluto. To overcome these problems, we are studying Delay Tolerant Networking (DTN), a new communication system. DTN has technologies that can be applied to the solar system Internet of Planet (IoP) in the future.

In this paper, we add delay and authorization information to

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the existing routing table reflecting the characteristics of DTN. The authorization field checks the IDs of neighboring nodes and increases routing reliability. The delay field reduces the overhead and speeds up routing based on the delay information of each node. We propose a routing method that can improve the efficiency of the existing DTN routing protocol using two additional pieces of information. Section 2 describes the ongoing research on the current DTN routing method. In Sections 3 and 4, we propose an algorithm and compare the efficiency of the algorithm proposed in this paper with that of the existing DTN routing method. Finally, Section 5 describes the conclusion and suggests some future research directions.

II.   RELATED WORK

A.   Three space telecommunications elements

Communication in outer space uses electromagnetic waves, which is also the method used on Earth, but there are also three key differences [8, 9]. Firstly, it uses high-power transmission using microwaves of higher frequency than the X-band, and which has higher linearity. Unlike in Earth's atmosphere, the space is mostly empty, so it is possible to communicate using a microwave of 8.4GHz - 8.5GHz band, which has strong signal even at a longer distance. For example, this frequency is higher than the 1.7GHz / 1.8GHz band that is mainly used in 4G wireless communication. When transmitting a signal, the direction of the ship or satellite is transmitted using a specific backward directional antenna. Since the energy of the electromagnetic wave is inversely proportional to the square of the distance, it is necessary to transmit the electromagnetic wave with a high output power in order to be able to receive at a considerable distance (such as for example for Voyager 1&2).

Secondly, it requires globally deployed base stations which can always receive signal despite the Earth's rotation. A single receiving base station can only receive signals from a fixed object located within a sector of 120 degrees, which poses significant problems for 24-hour monitoring. To solve this problem the United States has been building their deep space network since the early days of space exploration in 1950s. This system which can receive signals from all directions of the outer world 24 hours a day required huge antennas on three continents (California Goldstone, Madrid in Spain, and Canberra in Australia). Currently, not only Voyager No. 1, but also most distant objects around the Solar System are using this system.

Thirdly, this communication uses a high-sensitivity, low-noise receiver and a self-erroneous communication code. Signals from distant probes such as Voyager 1 are very weak, approximately a trillion times weaker than normal TV signal. To make matters worse, the noise is stronger in the receiving stations of the Earth than other signals of the outside world, such as radio waves from TV stations and radio stations. To filter out this noise and pick up the desired signal, we use a highly sensitive receiver operating at very low temperatures. In addition, errors are recovered from your received signal using a Hamming Code or parity bit to compensate for the error, so that
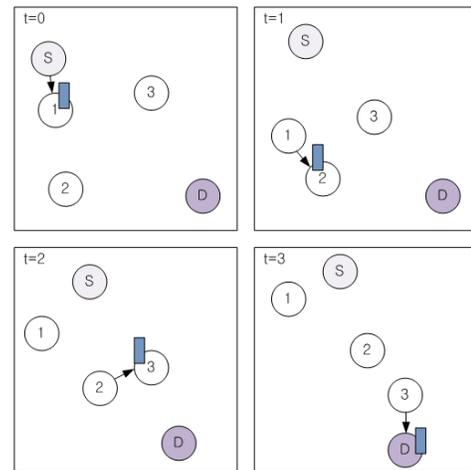

Fig. 1. Basic operation of DTN.

the original signal can be obtained.

B.   Delay Tolerant Networking (DTN)

A DTN [10-12], is a network capable of storing, moving, and transmitting data even in the absence of an active connection between the source and destination nodes. It can be applied to interplanetary communication, sensor networks, traffic information gathering, network or military ad hoc networks, making it suitable for applications that are sensitive to delay. The widely used TCP/IP Internet protocol is inefficient in space applications as it takes longer to send or receive data. For example, the expected time for sending data packets to Mars is approximately 3.5 minutes because of the distance. However, with TCP/TP it takes up to 60 minutes, and the network cannot not work if the delay exceeds 40 minutes.

Fig. 1 illustrates the basic operation of DTN. In the figure, t stands for time, S for sender (source planet), and D for receiver (destination planet). The position of the planet changes over time. By using DTN, in spite of huge differences of distance between planets, the data is temporarily stored and transferred to the next planet as shown in Fig 1. This way of transmitting data is termed "Transitive Networking". DTN automatically stores and transmits part of data, to nodes or satellites, to construct a much faster and more reliable network, which is pivotal to enhance communication. For the International Space Station (ISS), the communication systems had to be activated simultaneously for each node. However, if the other side of the communication is a satellite, it may not be possible to communicate from any location. Thus, by using DTN, communication is possible for each node and communication data is much simpler as it is used to write segment data. DTN is not only applicable in space, but it also helps to maintain effective communication in many different circumstances on Earth as for example in natural disasters caused by earthquakes or forest fires, nuclear power plant accidents, or deep-sea exploration operations.

However, the current DTN technology has various problems to be applied to a real space environment. The biggest problem is the transmission time between nodes. The data stored in the buffer is transmitted as the distance between both nodes approaches, and the period and transmission time are quite short.

In addition, the amount of data that can be transmitted at one time is also an important part. Currently, one-time data sending is very small amount, so it takes quite a long time to transfer even 1MB data. To solve this problem, [5] proposes a new DTN routing algorithm called Routing Based on Crowded Rendezvous Points (RBCRP). In their work, they reduce the network overhead and nodes of the network not require large quantities of memory for data buffering.

C. Current research trend in space communication

The principle of communication using a laser is the same as optical communication using an optical cable. The other point is that light passes through the space instead of passing through the optical cable. It is best if the optical cable is placed in the space, but this has been impossible until now. As such, NASA has been researching 'free space optical communication' (FSO) technology for a long time [13]. The FSO technology is a method of emitting laser-like light in an empty space and can only be used in obstacle-free spaces. Since the space between planets is mostly empty, applying FSO technology to space-based communications using lasers, seems like an inconceivable milestone to attain. Although laser-technology is evolving, it has not reached yet the level where it can produce a single high-power laser suitable for interplanetary long-distance communication. Using laser technology can be efficient for communication between Earth and Mars, but there is an inadequate part of communication between Earth and Pluto.

NASA has embarked on a project to test long-range laser communications systems to remedy these problems. The project called OCSD (Optical Communications and Sensor Demonstration) [15] is being tested using a tiny cube set (see Fig. 2). The cube set weighs 2.5 kg and is made up of small size module with dimensions of $10 \times 10 \times 10$ cm, for which the production cost is low and which despite its size, functions properly. It has everything you need for long distance laser communications. This set of cubes emits a laser with a 6 watts (W) output to transmit data at a rate of 200 Mbps from earth orbit to ground or vice versa. At this rate of data transmission, it is normal in a district with a high-speed network, but it is almost 100 times faster than the current wireless communication. However, there is a condition that the distance between nodes must be close. In the real space environment, node distance is very far, so more advanced research is needed. For this reason, DTN is used for longer distance communication.
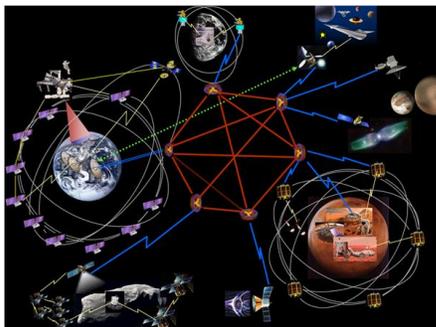

Fig. 2. NASA protocol for spreading internet across the solar system to reduce spacecraft communication lag times and broken connections [14].

The European Space Agency (ESA) is also working on similar research projects, which will test the AIM (Asteroid Impact Mission) [16] probe to trial laser communications farther than NASA's OCSD project. AIM is launched to probe asteroids that are close to Earth. It is expected to be launched between 2020 and 2021, when the asteroids are passing by, and the AIM is far from Earth. It is estimated that the distance will reach up to 75 million kilometers, and ESA's idea is to try to laser-communicate with the ground base at this distance. Hitherto, the largest distance of laser communication in space so far was in the range of the 400,000 km separating the Earth and a lunar probe. This project can also be advantageous in communications within the solar system. Even inside the solar system, it is only suitable for communication from Earth to Mars or Mercury to Venus. This is not an efficient way to communicate outside the solar system.

III. METHODS

A. Proposed DETN algorithm

The WSN and ad-hoc routing algorithm is widely used in DTN networks [17-21]. A wireless ad-hoc network (or IoT network) is a collection of distributed nodes. These nodes gather data from various sensors and relay that information to a central point through a wireless network. Therefore, the data can be aggregated and processed. These networks deal primarily with the transmission of small amounts of data that need to be transmitted very efficiently. The DTN actively exploits the caching of the router or node's storage, which depletes resources in many common instances.

Our delay-efficient tolerant network (DETN) scheme strikes out this deficiency by enabling a node to send its buffered data (collision-freely) as early as possible to reduce the delay. In addition, we deal with the dynamic data traffic by a more adaptive mechanism. Thanks to the smaller delay in the IoP environment, the adaptive mechanism also enables nodes to terminate their data transmission processes earlier depending on the data traffic to reduce the delay and save energy. Consequently, our DETN is delay and energy-efficient. The proposed scheme has two phases as follows: 1) Data Transmission Scheduling: this constructs a schedule for each node to transmit data toward the destination station (planet) under the condition of full data traffic. 2) Adaptive Data Transmission: defines a criterion based on a node which can adaptively stop its data transmission task in a sampling interval in accordance with the dynamic data traffic.

We define four states that the sensor node u can be kept during scheduling process, as in Fig. 3: • *Ready*: all children of node u have finished their schedule. • *Wait*: there is a children or descendant of node u that does not finish its schedule. • *Scheduled*: node u has just been assigned the time slot in Ready state. • *Finished*: node u has assigned enough the amount of its required time slot.

We design two algorithms for two targeted sensors nodes in the network: sink node and reporting node, and they elaborate each other's to make the scheduling algorithm works into iterations. For the sink node, its duty is to initialize the

scheduling process as well as to identify the end of that process. The sink first generates a Sch_req message and broadcasts it to all its neighbor to inform that the algorithm has been started. The Sch_req message has the format *(serial,tag)*, where *serial* is the number represented for the index of current iteration and *tag* is a value used to distinguish this control message from others. For another node *u*, all the leaf nodes are in Ready state, while the other nodes are in Wait state at the first iteration. When node *u* receives the Sch_req message from the sink, there are a set or subsequent procedure. The algorithm stops when the base station detects that all of its children have finished their scheduling, by observing the received Sch_done message. After finishing the scheduling process, each sensor node *u* would know its sending slots. The pseudo-code of proposed algorithm for *s*, *u* can be shown in Algorithm 1 and 2.

Under the dynamic traffic condition, a node may receive data at just some timeslots in its full schedule. Hence, it may not need to be active for data reception till the last timeslot of the schedule. Proposed adaptive mechanism that enables every sensor node to detect the completion of its mission of data transmission. The objective of such a detection is to minimize both the delay and the number of transmissions of the whole data transmission process. Under a dynamic traffic pattern, a node can conclude its data transmission at any timeslot starting from the anchor one onward. At the anchor timeslot, if a node has no data in the buffer to send, the node will no longer receive and send any data. Based on the discussion, the mechanism of adaptive data transmission is designed, in which every node performs a check on its buffer for any data as of the anchor timeslot. If the buffer is empty, the node may immediately switch to the sleep mode in the current session of data collection to save energy. Moreover, with this mechanism, the base station can conclude the data collection earlier, thereby improving the total delay. Our goal is to minimize the time of data transfer between distant planets (nodes).
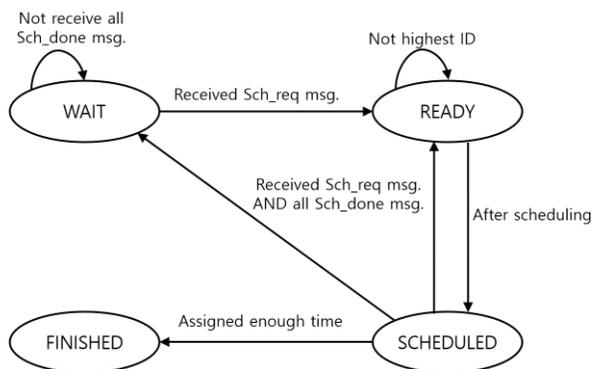

Fig. 3. State diagram of proposed algorithm.

Algorithm 1 Executed by the Base Station *s*

1: *s* sends a Sch_req message
2: **while** $\exists u \in Ch(s)$, State(u) = *Finished* **do**
3:   **if** *s* receives all Sch_done msg. its *Ch(s)* **then**
4:     *s* sends new Sch_req msg.;
5:   **end if**
6: **end while**

Algorithm 2 Executed by a Sensor Node *u*

1: **if** *u* receives Sch_req msg. **then**
2:   **if** *ID(u) > ID(v)*, State(v) = *Ready*, $\forall v \in CS(v)$ **then**
3:     *cnt(u)* = 0
4:     Sch-node(*u*, *buff* (*u*), *cnt(u)*));
5:     State(*u*) ← *Scheduled*;
6:     *u* broadcasts Sch_done msg.;
7:   **end if**
8: **end if**
9: **case** *Wait*
10:   **if** *u* receives Sch_req msg. **then**
11:     **if** $\exists v \in Ch(u)$, State(v) ≠ Finished **then**
12:       *u* broadcasts Sch_req msg.;
13:     **end if**
14:   **end if**
15:   **while** *u* receives Sch_done msg. from *v*, $v \in Ch(u)$ **do**
16:     *STC(v)* = *ST* (*v*);
17:     *buff* (*u*) = *buff* (*u*) + *cnt(v)*;
18:     **if** State(v) = *Scheduled | Finished*, $\forall v \in Ch(u)$ **then**
19:       State(*u*) ← *Ready*;
20:     **end if**
21:   **end while**
22: **case** *Scheduled*
23:   **if** *u* receives Sch_req msg. **then**
24:     **if** *State(v) = Finished*, $\forall v \in Ch(u)$ **then**
25:       State(*u*) ← *Ready*;
26:     **else**
27:       State(*u*) ← *Wait*;
28:     **end if**
29:   **end if**

B. IoP Simulation

Fig. 4(a) shows a square and Fig. 4(b) shows a rectangle network topology, respectively. The square topology was designed considering the vast outer space. It has the advantage of evaluating the performance of communication protocols before being applied to real space. The Rectangle topology is designed to test long-distance communication between space stations. There is an advantage that a real space station is installed and the communication performance between space stations can be tested. The x and y axes represent the distance and the unit in miles. To implement this, we randomly generate 100 sets of nodes whose size varies from 1 to 100 at the beginning of each sampling interval. Each set contains a random number representing the IDs of nodes that do not have data to send to the base station at that sampling interval. For each number of nodes, simulation is run more than 50 times and we average them to get the mean value. Random sensor node generates 1500 data packets that are sent to the sink node. The data packet size is 500 bytes. The performance evaluation is achieved through simulations using the well-known simulator NS-3 v3.23 [22]. We implemented the three routing protocols as a module. In the simulation, nodes are randomly deployed using Random Rectangle Position Allocator which is provided by NS-3.

The topology generator provides a quick and easy way to

create simulation code in an automated fashion. While using this tool, with the help of a GUI we can design our simulation scenario and generate the corresponding simulation code with few clicks. It provides an easy to use GUI from which we can add nodes, link, applications, and generates C++ simulation code for the ns3 simulation. By using this function, we established a large-scale wireless communication environment for DTN. The network created by simulation tool consists of large number of sensor nodes, all of which play similar roles. Existing DTN studies have two or more nodes within three miles. However, we set the distance between nodes at least three miles in consideration of the actual space environment.

IV. RESULTS AND DISCUSSION

Average response time, energy efficiency, and low error rate are important parameters in interplanetary communication [23, 24]. We compared the performance with the existing DTN algorithm in the three aspects mentioned above. To investigate the response time of the proposed algorithm, we experimented while changing the network packet index. We migrated the network data through the switch for the actual test-bed experiment.

Fig. 5 shows response time while changing packet index at the source planet of DTN. By using data migration software, we solved the problems of existing network data migration. It also improved performance and productivity, interim result

check/retry, job scheduling, efficient operation of large-scale data, cost reduction, and test-bed development time savings. The response time was irregular before the packet index was 50, but the response time was stable from 50 when the packet index was 50. This means that the performance of the proposed algorithm is stable after certain number of packet index. Through this experiment, we have confirmed that the proposed algorithm features a stable and fast network packet response time. In fact, in order to apply it to outer space, it is necessary to test performance over a longer time.

The response time between the existing DTN and the proposed technique was measured using a square topology (100*100 mile). We experimented by increasing the number of intermediate (relay) nodes from 1 to 15 (see Fig. 6). In other words, if the relay node is 1, the total number of nodes is 3 (1 relay + 2 pair). The time taken to transfer a total of 1 MB of data was measured. It took more than 100 seconds to transfer data until the number of nodes was 5. As the number of nodes gradually increased, the limited DTN algorithm showed a shorter average response time than the existing algorithm. In particular, it showed the biggest difference when the number of nodes was 10. It is confirmed that the proposed algorithm is very efficient when there is an appropriate amount of relay nodes in interplanetary communication in the solar system.

We experimented with the overall status of the network. Fig. 7 shows throughput, packet loss rate, and latency. The red solid

(a) Square topology and its corresponding node.

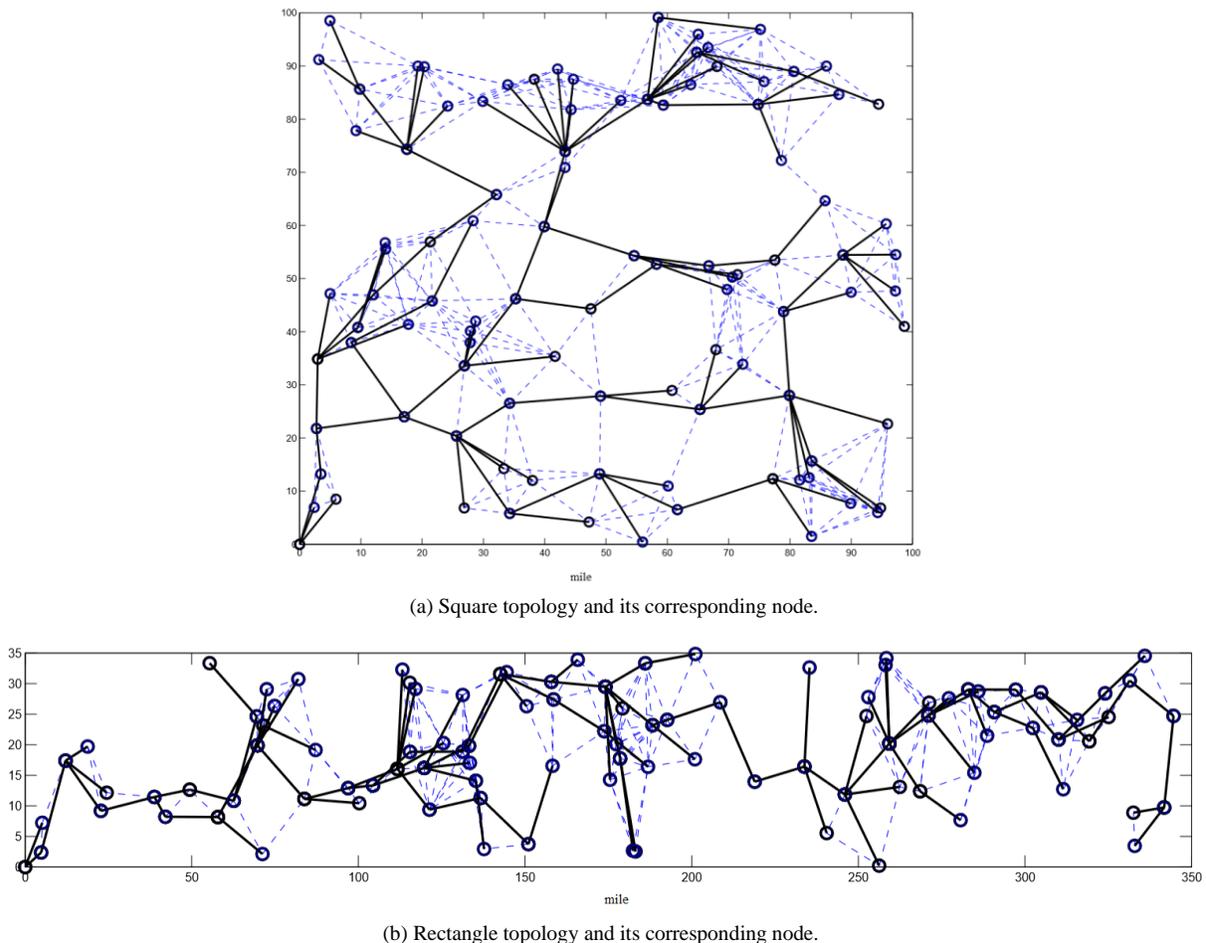(b) Rectangle topology and its corresponding node.

Fig. 4. Different types of DTN network simulation topologies.

line is the QoS measurement in a typical DTN network. Notable in this result, is a significant amount of packet loss over time. Also, we can see that the network latency occurs steadily after a certain period of time. The blue solid line is the result of applying our algorithm to the DTN network. Throughput is stable and network latency is considerably low. The network latency does not occur constantly, but it is small and short when it occurs. Considering various conditions, it shows that the proposed algorithm works well within an IoP environment which processes a huge amount of data. Due to the nature of the sensor network and likely applications, it is very important to transmit data in a short time while minimizing energy consumption, which is a key element in outer space. In this aspect, the proposed algorithm showed faster data transmission capability while minimizing system resource consumption compared to the existing DTN.

We finally tested the energy efficiency of the DTN network. Energy efficiency in DTN is also an important check factor. Fig. 8 shows the energy efficiency for DTN. Initially, large amount of energy is consumed at the time of node activation, and then a certain amount of energy is consumed at the time of data transmission. To minimize the amount of energy consumed during node activation we need a strategy for optimizing battery usage for planet-to-planet communication.

DTN is an internet protocol that is created assuming connection in space subject to long communication delay. Information is transmitted in a manner different from TCP/IP, which assumes that the connection is continuous. For example, if a ship enters the shadow of a planet, the connection may be dropped, in which case the DTN is designed to keep the network node intact and to prevent loss of information without destroying data packets. However, existing communication protocols such as mobile ad hoc networks and sensor networks do not properly reflect DTN-specific characteristics. In addition, the routing protocols designed for DTN are also based on non-realistic assumptions such as random mobility, which leads to poor efficiency in actual IoP environment.
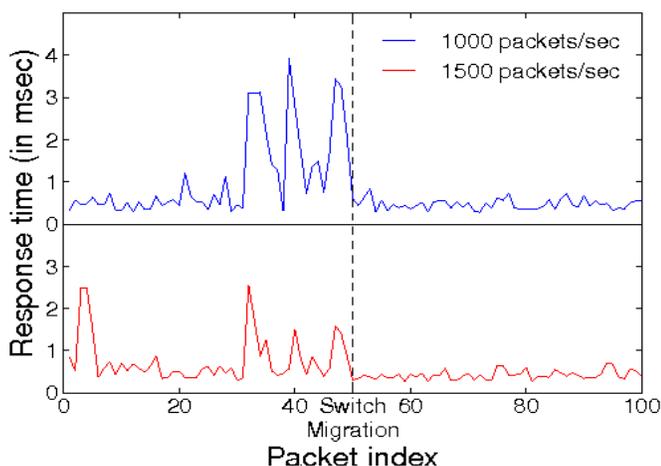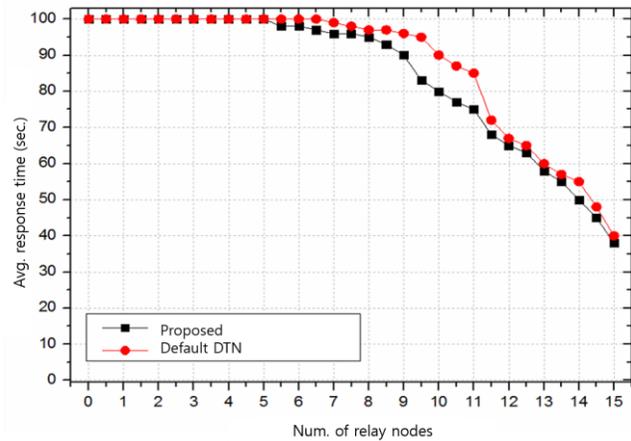

Fig. 5. Response time while changing packet index.

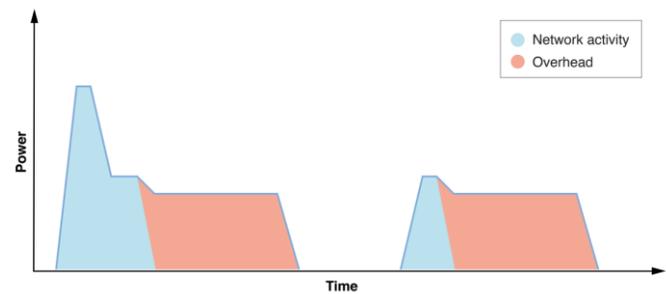Fig. 6. Average response time while increasing number of intermediate (relay) nodes.

Fig. 8. DTN network overhead.

V. CONCLUSION

The delay in DTN is caused by the characteristics or instability of the transmission medium itself, or by the mobility of the host. Therefore, the concept of DTN can be broadly applied to existing networks such as ad hoc networks, sensor networks, and vehicle networks that are prone to such delays. Recently, much research has been done on DTN-based routing schemes. Although these schemes guarantee a certain degree of message delivery success rate among nodes with random mobility, they still have problems in terms of transmission probability and overhead in the case of message delivery between a single host and a host. Also, performance test in actual IoP environment is required.

This paper proposes DETN to find an efficient relay node in DTN to solve this problem. The proposed algorithm analyses the network status by using delay and authorization history, in order to select an efficient relay node from DTN. In addition, since the actual movement of nodes differs from the model used in the simulation, there are certain rules. Through the experiment, the proposed DETN algorithm showed faster average response time, less energy consumption, and less error rate than the existing DTN. We are planning a comparative analysis with the recently introduced DTN protocols. If further research is carried out and considering relay node selection according to buffer and energy of node, more stable DTN routing will be possible. If we overcome this, we will actually be able to connect the planets with the Internet – hence IoP.
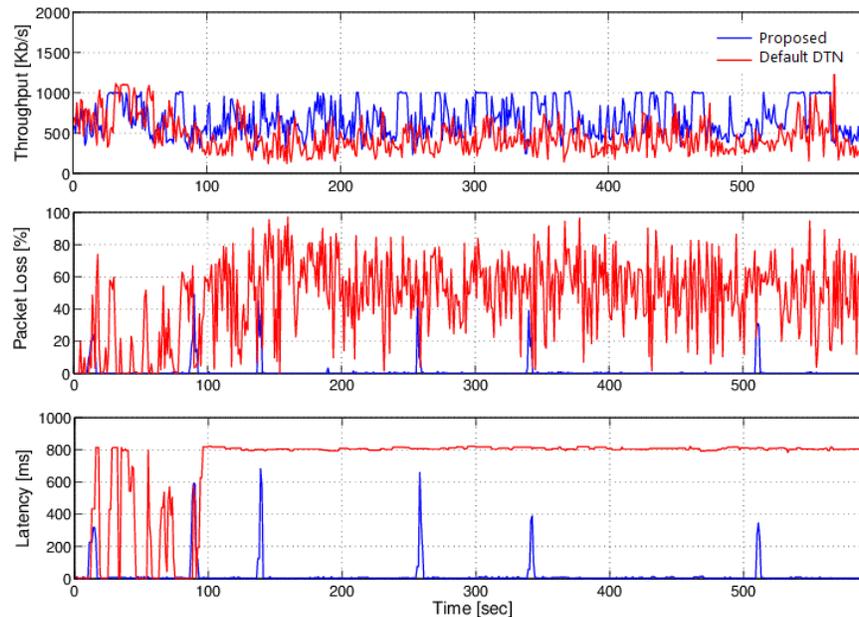
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Fig. 7. Throughput, packet loss rate, and latency of QoS traffic flow for proposed scheme.

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