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ORIGINAL ARTICLE

Enhanced disruption tolerant network (DTN) framework for improving network efficiency in rural areas

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Abstract Telecommunication is a problem in certain rural regions and deep rural regions in Malaysia because the absence of the standard communication infrastructure due to geographical and socio-economic limitations. The dense forest, mountainous regions and streams along the rural regions contributes to the main factor of the limitation of erecting a communication infrastructure. With the absence of infrastructure, communication capability is limited and this causes some villages to be disconnected. This condition is also known as intermittent connectivity whereby not even cellular networks can reach the villages prohibiting them from calling, texting and surfing the Internet. Additionally, the low-income status of the rural population and the lack of interest in technologies while having lower population and sparse village placement also adds into the factor of not erecting a communication infrastructure. This in turn, inhibits the development of IT sector in rural regions and hence causes the digital divide in Malaysia. To solve the intermittent connectivity issue while catering to the absence of infrastructure and socio-economic status of the rural populace, an enhanced delay/disruption tolerant network framework (DTN) is proposed in this research study. The aim of this paper is to explore the current trend and state-of-the-art of DTN by conducting initial experiments to design the DTN framework for improving the efficiency of internet connection in rural sites. In this paper, specific focus is provided for ION-DTN technology developed by NASA for conducting experiments and to develop optimized prototypes for designed DTN framework.

Keywords Delay tolerant network · Internet · Efficiency · Framework · Efficiency · Rural areas · Internet of Things

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1 Introduction

In the world today, communication comes in many forms; starting with the simplest form: verbal talks, written letters to the ones that require electronic devices such as emails, telephone call and text messages. The communication technology that provides us with the various ways of communication is none other than the cellular network and the Internet. Need to thank these technologies to the point that they are being taken for granted and many people have forgotten how hard it used to be to stay connected. Unfortunately, while these technologies are widely available practically everywhere, there are places where this seemingly common technology are fairly unstable and may even be non-existent. These places are none other than the rural regions in almost every country in the world where intermittent connectivity is a problem. Intermittent network condition or intermittent connectivity refers to the situation where an end-to-end connection between the source and destination is extremely unstable or unachievable which inhibits a TCP/IP connection that will form the transmission link. As a result, should a connection be successfully formed, data packets will get dropped frequently due to unstable links, causing the data to be malformed or worse, the connection could not be established in the first place. While each country may face the same intermittent connectivity issue, they face different geographical challenges (Comer 2018; Diwan et al. 2016). For flatlands and mountainous regions, balloon mesh network may be a suitable solution; for dense forests, TV whitespace maybe it; but for places with a more extreme conditions where a mixture of the above appears and the absence of existing infrastructures pose as a problem, a technology more robust is required. Research works related to Internet of Things and fog computing are been growing rapidly to produce emerging applications such as interplanetary networking, wildlife monitoring, vehicular communication, military system and communication in rural areas (Kishor and Chakraborty 2021a; Kishor and Chakraborty 2021b; Kishor and Chakarbarty 2021c).

In the domain of Internet technologies, many people would know about the standard Internet technologies like the dial-up access, DSL, fibre optics and 4G LTE cellular networks. Few people would know about satellite networks. Some rural Americans from the 90's might know about power line-based networks that has been discontinued for over 7 years now. Some African in recent years would know about balloon mesh network, specifically Project Loon by Google subsidiary company Alphabet X. Many tech-savvy younger generations of the urban populace may have heard of vehicular networks that empower intelligent transport systems (ITS) (Comer 2018). Enthusiast, smart home and smart farm owners may have heard of low-powered wide area networks that runs the Internet of Things industry. Each of these technologies aimed to provide Internet communication capability to the rural population with different approaches and each comes with different weaknesses and thus a one-technology-for-all of the rural communities has yet to be found. Arguably, satellite networks can solve the whole problem but the sheer cost of one deployment deters the idea. While some technology like TV whitespace can provide up to 10 KM wide network coverage, it may not be able to reach scattered villages more than the said distance. In deep rural areas where the population are cut-off from the main land by dense forests without road access, rivers and mountains, a technology more robust and handle extreme network condition well is required.

To consider these requirements, inter-planetary network (IPN) was investigated. The core of the IPN was based on the delay/disruption tolerant network (DTN) Architecture. The term delay in DTN implies that the network will attempt the transmission through a variable length of time, which can be seconds, minutes, hours, days or even months. On the other hand, the term disruption in DTN refers to the ability of DTN to successfully transmit data in unstable links between the source to destination. In short, the main concept of DTN is the ability to transmit data where an end-to-end transmission is not available at all times and thus utilizes a store-and-forward bundle mechanism in specialized routers. In this paper, to improve the efficiency of internet connection, enhanced disruption tolerant network framework is proposed. This study describes the experimentation plan to get the best minimum viable product by comparing each setup to an efficiency model. Some experiments were based on the early DTN performance evaluation, NASA's experimentation and some are based on the IoT experiments. The experiments mainly observe the range, delivery ratio and time taken to complete a transmission. The optimal settings are observed and adjusted on every phase of the experiment. With the completion of the experiments, a generic framework to create a DTN structure and applications are built as the final outcome of this preliminary research study. The paper is organized as follows: Sect. 2 explains the research challenges for this study; the research objectives are framed in Sect. 3; In Sect. 4, preliminary experiments were conducted to design the enhanced disruption tolerance network framework. Finally, conclusion of this study was made in Sect. 5.

2 Research challenges

The communication means and the Internet in rural areas are slow or non-existent at all in certain countries and/or region. This is due to the lack of infrastructure and the cost of setting up one [Kishor and Chakraborty 2021b]. Both of these factors are further affected by the geographical constraints; i.e.: building and maintaining a communication tower may not be feasible in a deep forest and river-cut-off lands where some deep rural community resides. Furthermore, the rural and deep rural population have low-income status which also affects the building of the infrastructure (Comer 2018, Seth 2018; Perumal et al. 2017; Goncalves Teixeira et al. 2021); hence creating the intermittent network condition. With limited infrastructure, intermittent connectivity and geographical limitations, installation of standard and alternative infrastructures will be difficult and costly to deployed (Suresh et al. 2021). As such, an alternative that require minimal infrastructure and works with intermittent network condition is required; for this infrastructure DTN architecture is found to be the best solution. While DTN may seem a perfect fit to these problems, the only successful implementation so far has only been achieved by NASA through ION-DTN. There has yet to be any successful DTN framework that is being widely used in terrestrial network although many implementations and pilot studies has been done in this area. There were few research questions carried out for this preliminary study are as follows:

1. How to justify a delayed network framework despite the futuristic high-speed Internet hype?
2. What kind of data will be transmitted and how long will the data stay in persistence?
3. How to ensure the integrity and security of the data before, during and after each transmission?
4. How can transmission of data be performed using the cheapest and most widely available device such as Android?

3 Research objective (s)

The main objective of this research is to design an Enhanced Disruption Tolerant Network (DTN) Framework to solve intermittent connectivity issue in rural Malaysia that is causing the digital divide. To achieve this objective, a series of sub-objectives are framed, which are as follows.

1. To review existing architectures and frameworks in DTN implementation and their maturity
2. To validate the most matured and stable version of DTN through a series of experiments
3. To design a framework for the components within DTN to achieve a minimal viable product in the client, server, router and carrier nodes that will be combined into a full DTN ecosystem

By completing these objectives, it will serve as a proof of the current maturity level of DTN is enough to create a production system. With that, a digital platform that is envisioned to include the rural and deep rural communities in Malaysia can be developed in the near future.

4 Proposed DTN framework

This section briefs the conceptual model of the proposed framework and its workings. Experiments are carried out throughout the preliminary study and prototypes are made to validate the experiments, a general framework to create a full DTN system is proposed in this paper.

In Fig. 1, the data movement can be between nodes are achievable via wireless, wired or carrier-based medium. The bundle protocol will be installed on every node to allow store-and-forward mechanism. As with any DTN implementation, the naming convention follows the rule of a state.region.type_id. The concept works different to other existing works by implementing a centralized system where applications can be built on top of it and served as a module of the proposed DTN model. The vision of this model is to be able to create modular apps that can be plugged-and-play on every regions of Malaysia where the framework is implemented (Figs. 2, 3).

4.1 Considerable technologies

The considered underlying software would be ION-DTN developed by NASA for Interplanetary Network, in favor of the SPINDLE and DTN2 due to it having active development status and more functionality while claimed to be adhering to international open standards as outlined by the consultative committee for space data systems (CCSDS) (Unnikrishnan et al. 2016) and the IETF approved RFC 5050 Bundle Protocol Specifications (Scott 2019).

DTN in some smartphone-based implementations like FireChat (Anon 2019) transfers the data between smartphone devices. In other words, every android devices containing the app will become the router itself. While this may seem effective with a decentralized architecture, the app only supports functionalities within FireChat app itself as it recognizes other devices with FireChat installed. On the contrary, a centralized architecture is more preferred to build a generic framework upon so different types of data from different applications can be ensured to be delivered safely and successfully.

4.2 Hardware and software requirements

4.2.1 DTN server backend services at DTN server node

The DTN Server or TBS must employ a powerful computer to process data that comes from multiple VBS. The server will be heavily in charge of retrieving and disassembling the data and reassemble them once more when a response data is received from the Internet. It is also responsible to sort the data out based on the VBS it came from.

- ION-DTN to provide the bundling protocol
- NodeJS (AdonisJS) / PHP (Laravel) to provide the API
- NoSQL Database (Cassandra) to provide database
- LPWAN (LoRa) to provide long range signal transmission

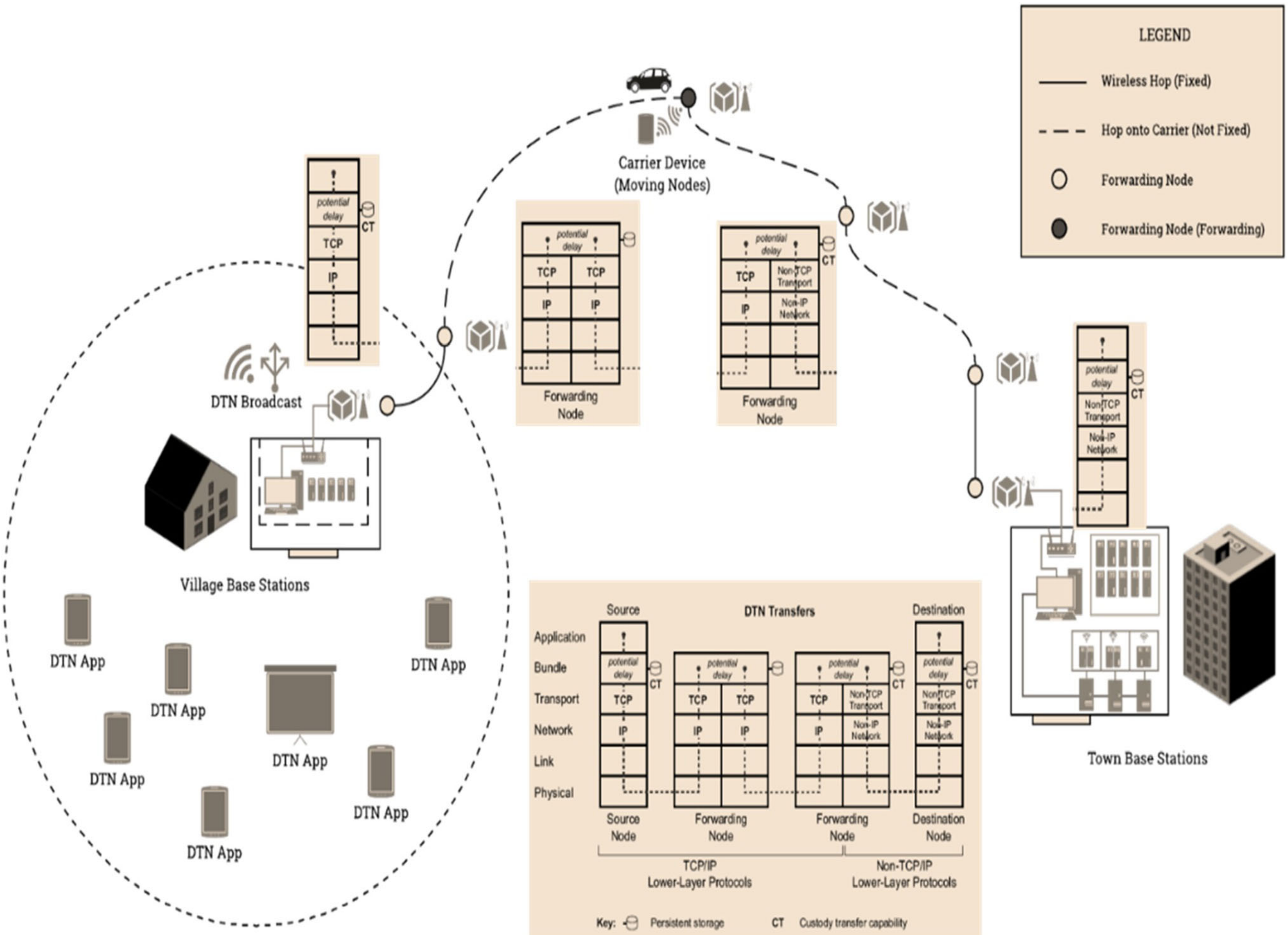

Fig. 1 Shows the conceptual model of the DTN framework

Fig. 2 Shows decentralized forwarding architecture described in P2P network (Fire Chat) vs centralized architecture described in Client/Server network

4.2.2 DTN client app (frontend services) at DTN client node

The DTN Client need not be powerful but decent enough to run the provided app. The client app will either be a desktop-app, mobile app. Should it be a web app, the following lists down the development stack. The user interface will have a preset functions and interactions available. When the user requests for data from an online source, then the DTN functionality will trigger. There can possibly be two types of apps at this edge of the network; (a) for the data to converge at one central point and send out in surrounding areas and (b) for the surrounding users to use the DTN app without having to go to the convergence point.

4.2.2.1 Desktop app The Desktop should have a minimal specification which may include an AMD Ryzen 3 1300X and an 4 GB RAM (+ 4 GB swap space) with a 256 GB storage and a Ubuntu Linux Operating System.

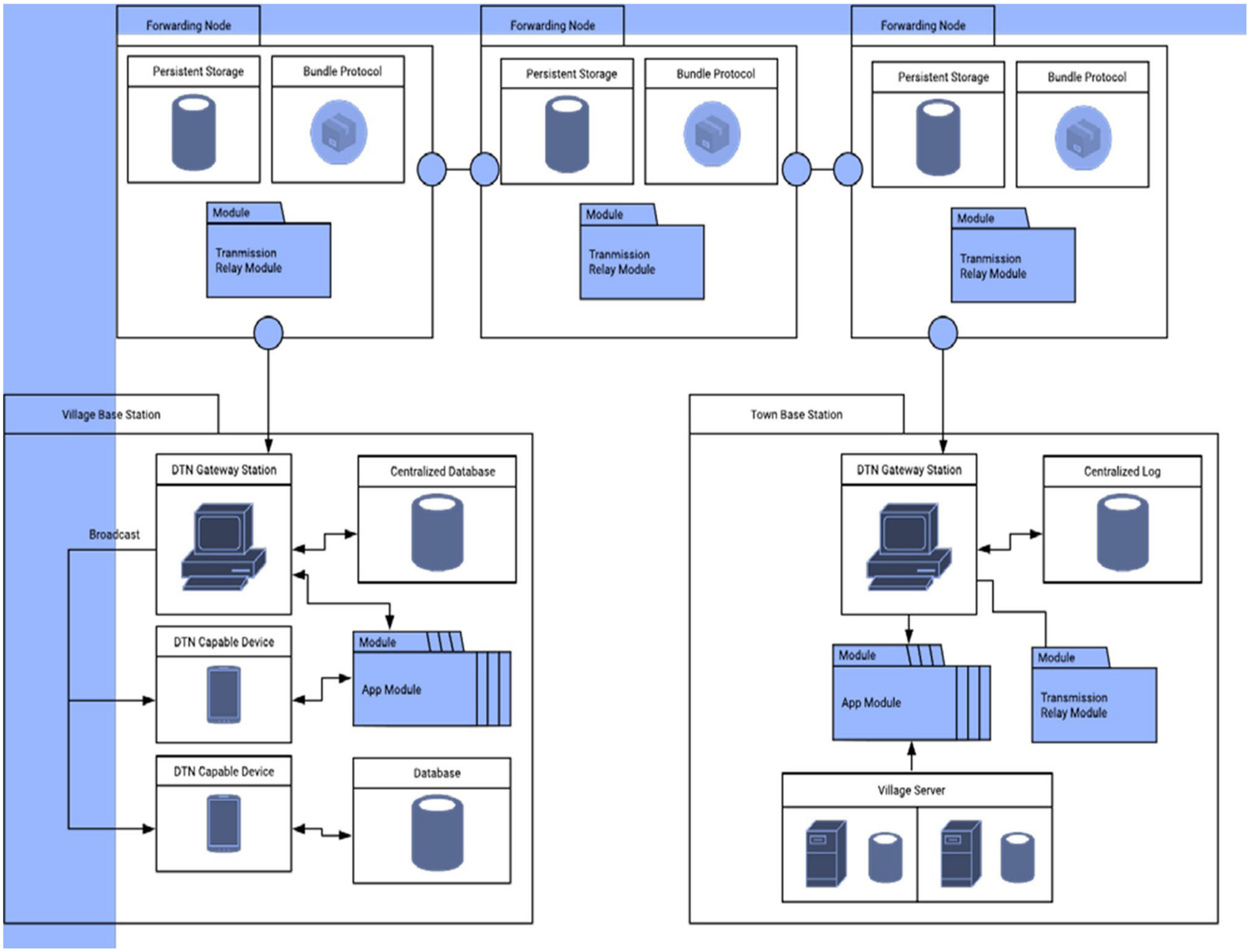

Fig. 3 shows the proposed components within each part of the DTN framework

- ION-DTN to provide the bundling protocol
- NodeJS (AdonisJS) + Electron to provide desktop user interface
- NoSQL Database (Cassandra) to provide database
- LPWAN (LoRa) to provide long range signal transmission
- WiFi (Long-Range WiFi) to provide connection for DTN mobile app to transmit data

4.2.2.2 Mobile app

- ION-DTN to provide the bundling protocol
- Native Android (≥ API 19) to provide app
- NoSQL Database (JSON / Realm) to provide database

4.2.2.3 Wireless transmission method at carrier devices and DTN forwarding node Wireless transmissions will mainly be tested between one DTN Forwarding Node to another and carrier devices, which is shown in Table 1. Transmissions at this stage will face more experiments to proof the different transmission media can and will work regardless of the difference in the protocols implemented in the lower OSI layer. Among the transmission medias to be

Table 1 shows a comparison of wireless transmission medium

	Bluetooth LE	WiFi direct	Long-range WiFi	LoRa
Data Rate	125 kbit/s–2 Mbit/s	> 54Mbits/s	> 100 Mbps	250bit/s–11kbit/s
Range	100 m	46-100 m	11 km	> 2 km (NLOS)–21 km (LOS)
Power	0.01–0.5 W	2—20 W	66–132 W	0.025 W
Frequency	2.4Ghz	2.4 or 5.0Ghz	2.4 GHz, 802.11 b/g/n	863–870 MHz

tested include Bluetooth LE, WiFi Direct, Long Range WiFi and LoRa. Although some may argue for not including Li-Fi due to its almost-infrared light/laser based medium in contrast of the radio wave medium, it is known to have short distance and work well only in certain conditions like room-like environment. The carrier devices will be based on Android to employ an affordable yet powerful media for the people to use. The carrier may or may not be from the village. Since the carrier node is and Android smartphone, the underlying hardware is not an issue. The DTN forwarding nodes need to be small and easily hidden to prevent from being stolen. These nodes need to be low-powered to accommodate use cases where no direct power can be acquired and forced to rely on battery. These nodes may use Raspberry Pi Zero and a Bluetooth or Wireless Network Interface Card (WNIC) to allow the data hopping.

4.3 Phase 1: environment setup

The first phase is to ensure the minimal prototypes are working properly and able to send and receive data. At the same time, the first phase aims to find the cause of failure of transmission and its solution. In both setups, a minimum of 2 gateways (client/server), 1 carrier devices, 2 DTN forwarding nodes. There are 2 types of DTN nodes; DTN client node that serves the application layers to the villagers and DTN server nodes that in charge of handling data exchange from the town base stations to the Internet. Additionally, to test the viability of multiple child clients, a transmission via WiFi hotspot and Wired LAN will be attempted. The types and content of data used and transmitted will be kept constant while the location of DTN nodes and route of the device carrier and number of DTN forwarding nodes will be changed from time to time. The experiment is conducted with the minimal setup without optimization at different locations within the university campus.

4.4 Phase 2: optimization and performance evaluation

During this phase, the performance will evaluate the transmission options to decide on whether to use Bluetooth, Wi-Fi or LoRa in the final setting. These tests will be performed on: the carrier devices, DTN forwarding and edge nodes. These devices will be out in the open, therefore, they will be equipped with a waterproof casing. The tests mentioned in this phase do not have to include the successful transmission from the source node to the destination node. These tests are meant to test the efficiency and successful delivery ratio over different sets of environments between two or more forwarding nodes. The optimization phase will hopefully improve the speed and efficiency of transmissions and reduce the number of packet/bundles drops per second.

4.4.1 Losses through obstacles

This test is intended to observe the transmission capability during custody transfer. This test will be conducted at various undisclosed location with characteristics suitable to the said condition. The location should be in a (1) forest with a lot of trees, and (2) in the city area where the device will be place behind one or more obstacles. The focus of this test will be to monitor the successful delivery ratio and packets drop per second.

4.4.2 Range test in forest and cities

This test is intended to observe the behaviour of the data in persistence and custody transfer operation. This test will be conducted at various undisclosed location with characteristics suitable to the said condition. The location should be in a (1) forest with a lot of trees, and (2) in the city area where a lot of other Internet access points exists. The focus of this test will be to find the optimum range in each condition.

4.4.3 Attenuation in water

This test is intended to observe the packet lost due to uneven weather like rain. For the method to conduct this test, the forwarding nodes will be placed within a certain distance away from the user and surrounded by fog which may be induced by steam. The focus of this test will be to monitor the successful delivery ratio, the maximum range achieved and time taken for the content delivery.

4.5 Phase 3: system testing

With the optimal conditions and settings are made on each device, the system is tested at full scale. The scenario simulated will have almost the same environment as the rural areas where the distance between source and destination is roughly 20—30 km apart. The metrics to be tested includes but are not limited to:

- Successful delivery ratio
- The time for the DTN apps to update
- Interference during transfer at forwarding nodes
- Interference/attenuation during bad weather at forwarding nodes

4.6 Phase 4: DTN framework development

The intended framework to be created should include the four main components of the proposed solution:

A. The Village Base Station which are in charge of collecting the data from surrounding DTN capable devices (child nodes) and label them accordingly before periodically bundling them into data to be sent to Town Base Station.
B. The Town Base Station which are the central point which connects the data retrieved from each Village Base Stations to the Internet resources it points to.
C. The Forwarding Nodes or also known as a Throwbox which can be a moving or stationary points (devices) where it can take custody of the data that hops in from one node and relay it to the next node.
D. The App Module which should contain the separate app that can be viewed from the DTN Client Nodes and its children nodes. This may be written in Android Java/Kotlin language or NodeJS. The main functionality is to make it recognizable and usable at the correct Village Base Stations.

DTN frameworks and libraries are not new. In the existing works contains the technologies like Bytewalla (Ntareme 2011) and ORWAR (Herbertsson 2010) which are applications and libraries made to accommodate DTN usability. The most popular use case of these technologies includes transmitting emails and sensor data (Abdelkader et al. 2016). In militaristic applications, DTN has been used to transmit files, voice and text messages (Sehl 2013). In some cases, the DTN capability is included from scratch and almost hack-ish (Sehl 2013). Therefore, creating a generic framework to build DTN applications on top of well-built software like ION-DTN is needed to ensure a standard on the DTN applications and is the main contribution of this preliminary research study. Therefore, initial experiments mainly observe the range, delivery ratio and time taken to complete a transmission. The optimal settings are observed and adjusted on every phase of the experiment. With the completion of the experiments, a generic framework to create a DTN structure and applications are built as the final outcome of this research project.

5 Conclusion

In this paper, DTN framework was proposed for improving the efficiency of internet connection. To proof the current stage of DTN is ready for the terrestrial networks, experiments, prototype and framework has been designed in this preliminary study. Each of the outcome will serve as a validation to the motivation of this research, to develop IT sector in rural areas where intermittent connectivity poses as a problem. The preliminary experiments are based on similar fields of study and inspired by the field of Internet of Things and the success of NASA advancement in this field. The prototypes are developed based on the predecessor apps such as Butewalla and ORWAR. The results from the experiments are used to develop a generic DTN framework.

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Declarations

Conflict of interest The authors declare that they have no conflicts of interest to report regarding the present study.

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Human and animal rights The Research not involved human participants and/or animals.

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