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ORIGINAL ARTICLE

Comprehensive literature review on delay tolerant network (DTN) framework for improving the efficiency of internet connection in rural regions of Malaysia

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Abstract This paper brief in detail the technology reviews of current available technologies and literature reviews that starts with the history of the Internet and the understanding of the working of the Internet through a conceptual model of TCP/IP and OSI models, the numerous technologies developed to cater for different connectivity environments and recent popular topics in the field of communication technologies. Detailed review is done on the subject of Delay-Tolerant Networking (DTN), the chosen technology from which the intended framework can be proposed for improving the efficiency of internet connections. From these literatures, comparisons are made to find the best possible combinations of technologies to design a minimum viable product, followed by a generic DTN framework.

Keywords Delay tolerant network · Efficiency · Internet

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1 Introduction

Before the existence of internet, there are multiple Local and Wide Area Network (LAN and WAN) technologies already existed but were kept private within each different company where these technologies are patented and kept as trade secret to allow only computers from the same company to communicate and prevent other companies to build on top of these technologies. The software Transmission Control Protocol/Internet Protocol (TCP/IP) were created to serve as an open communication system to allow computers of different brands to communicate with each other. This would later be known as the Internet after getting widespread use after being adopted by DARPA between 1980 and 1985. This technology soon grew at a fast rate where the number of computers equipped with TCP/IP software at least doubled each year which now reached to billions of users throughout the world mainly used for entertainment, production, smart city planning, work and communication (Comer 2018).

Before the Internet become widespread, there were multiple means of communications such as letters, messengers, the telegraph and the telephone. The telephone was a revolutionary technology that enabled two separated people to communicate by voice—this was marked as the first generation (1G) of the communication technologies. Next, comes the text messages (2G), video call capability (3G) and then the cellular network broadband (4G) which enables surfing the Internet from mobile devices (Comer 2018). In recent years, researchers have reached a new breakthrough (5G) that will enable an even faster Internet connectivity through the study of millimetre *wave* technology (Hill 2019).

Although not directly, the evolution in communication technologies also affected the evolution of the Internet access technologies that started with dial-up access which transmits the data through analog signals and utilizes the narrowband frequencies. Which then followed by more efficient technologies that transmit data over digital signals and over the years, more development was made towards using the broadband frequencies (Comer 2018). These technologies are more known as Digital Subscriber Line (DSL) Access, Cable Modem Access Cable and succeeded by the optical fibers of which are also known as Fibre-to-the-X (FTTX). At the last mile, these technologies are often broadcasted to a limited area through wireless technologies like the WiFi and ad-hoc networks.

While the technologies progressed steadily in the passing of years, not everyone received the luxury of the updated technologies. Even within first world within countries like the United States of America and United Kingdom there exist disparities in the accessibility to the Internet access technologies. In 2017, many rural areas within the United states still relied on dial-up access technology which was the only choice of Internet access due to being landlocked and too far to reach for the last mile technologies (McKissen 2017). In third world countries like the ones in Africa are also facing the same difficulty (Reynolds 2018). The limitation in the reach and available technologies motivate researches and usage of alternative technologies such as balloon mesh network and satellite networks among others. This disparity in access to the technologies is commonly known as the digital divide.

The digital divide has more factors than just the access technologies and geographical limitation. In fact, income and lack of interest are part of the contribution to the cause of the digital divide. While not all of the rural areas are limited in terms of access technologies, the age and income level of the community affects the adoption of the technology with the villages with more elderly tend to reject ICT and considers them as luxury rather than necessity (Soltan 2019; Taylor et al. 2006). To reduce the burden on the rural communities, many countries have Universal Service and Access Funds (USAF), a dedicated communal fund to expand the connectivity opportunities to rural communities (International Telecommunication Union 2013). However, Yoti Head of Social Impact, Ken Banks emphasized the failure of the USAF incentive was inevitable due to the nature that bridging the digital divide is expensive and makes little sense in economic term because these disconnected communities are will unlikely spend a large amount due to the low income in the first place (Seth 2009).

The aim of the paper is to explore and detail the different literatures and technologies related to delay tolerant network architecture for improving the internet connection in rural regions. The paper is organized as follows: Sect. 1 briefs the internet network and communication technologies; the alternate internet network architecture is explained in Sect. 2; Sect. 3 details about the delay tolerant network; Recent literature's and specific reviews on DTN was briefed in Sect. 5; Conclusion was made in final Sect. 5.

2 Internet network and communication technologies

To understand why building a solution for digital divide is difficult, an understanding of how a standard network works is essential. A network is achieved by linking computers between each other through wired or wireless medium. This will enable both computers to transmit data to each other which normally is achieved with a TCP/IP protocol. These data will be translated in the form of websites, emails, graphic, text and video files. Before the data can be received on the other end, the data will pass through each layer inside the model and within the layers have different protocol. This will happen down to the Network Interface layer. After that the data packets will then hop through many routers until it reaches and received at the destination. It will then go through each TCP/IP model layers from the Network Interface layer up to the application layer. This signifies the data transmission is done and communication between two computers is achieved. It is important to note that the data packets have to hop onto so many nodes in between the source and destination to make a successful connection; this is referred to a successful end-to-end connection, which is shown in

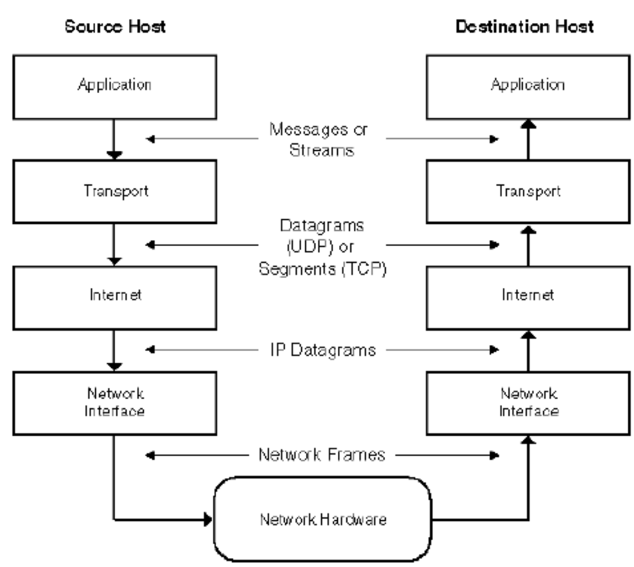

Fig. 1 Shows direction of data transmission from end to end (Eltaeib 2015)

Fig. 2 Shows an illustration of a VSAT connection of a Satellite Network

Fig. 1. However, this is a difficult to achieve scenario for rural areas where the infrastructures are most of the time not available. To address this issue, many alternative network architectures are introduced over the years for different applications.

3 Alternative network architectures

3.1 Satellite network

Satellite networks are infamously known as the last resort that only the remotest and desperate would consider getting. This is due to the availability of connection to almost anywhere in the world but suffers from the lack of speed and capacity while being very expensive (Hurst 2018).

There are many satellite connections provider that provides telecommunication service and even internet anywhere in the world. Within the service, there are different types of devices that serves different purposes in regards to using the satellite networks to transmit data whether in voice, text or the Internet. Very Small Aperture Terminal (VSAT) provides Internet access by installing a dish normally on the rooftop at a certain angle that then connects to an adapter within a building like a typical router, which shown in Fig. 2. Another option known as Broadband Global Area Network (BGAN) allows users to connect to the Internet through satellite networks more portably with the speed as a trade-off. Finally, Iridium satellite constellation that provides voice and text messages over the L-band often comes in the form of a satellite phone (Hurst 2018).

Iridium	BGAN	VSAT
Phone call & SMS	Speed from 100 – 650 kbps	2–4 Mbps
Very portable	**Portable**	**Not portable**
Work out of the box	Need to adjust to point to satellite	Implanted on a building, connected by wires

In early 2018, SpaceX launched two new satellites: Tintin A & B as the testing for the viability of building a successful 4,425 Ka/Ku band LEO constellation. If successful, this would promote the use of Ka/Ku bands instead of C bands which uses cheaper materials and may reduce the pricing of satellites network, making them more affordable for the lower income population (Sheetz 2018).

While satellite network is an effective alternative to bridge the digital divide due to its reach and decent speed, it is realistically impractical due to the sheer cost of its installation and maintenance. Moreover, the more decent ones can be quite pricy and billed annually. This would be a viable solution only if the rural population are high income earner or the government would significantly subsidize the network as in the case of Greenland (Suresh et al. 2021a) and Falklands (Jones 2017).

3.2 Dial-up access

In the early years of the Internet, Internet Service Providers (ISP) mainly offered dial-up accesses. Different from most Internet services nowadays, dial-up falls under the narrowband categories. The mechanism works differently to modern broadband like the FTTX where the modem attached to the computer will go off hook emulating the action of dialling a specified number to a modem at the ISP. The data exchange happens when the user modem communicates with the ISP modulate audible tones, which is shown in Fig. 3 (Comer 2018).

Theoretical reasons to why people are still subscribing to the dial-up internet services may be due to one or more of the following reasons: The area of living does not have Internet access due to the lack of infrastructure, the high cost of broadband subscription not affordable to lower income rural people and the absence of the reason for a change since some rural people do not depend on the Internet for work and living (Wong 2017). While some may argue that *slow Internet is still better than no Internet* it is half-true, a post written by Digital Trends employee proved otherwise. He showed that to just to get dial-up access up and running is a bad experience and that is not including the frustration when using the service. Using dial-up requires at least one minute and 15 s to load

Fig. 3 Illustration of communication between the modems that forms dial-up network (Comer 2018)

google.com without a search keyword. Arguably, if the usage is just to view emails and news from a very low-resourced website, then there is no problem in using this service (Wong 2017).

While the rural population in the United States subscriber reaches 2.1 million by late 2017, this technology is not the answer to fix the digital divide. Although the connection speed is low, it still enables the rural people to get news and emails. Using a dial-up internet service however, limits the use of Internet compared to how the urban people uses the Internet like streaming videos and social media. Moreover, In Malaysia, TM, the ISP company has terminated the service as of October 2017 and even if its arguably useful, it is not available anymore (Mitchell 2018).

3.3 Cellular wireless access system

The term cellular system is more familiar to most as mobile data in mobile telecommunication subscription plan or a SIM card (Subscriber Identity Module). When subscribing to the said subscription, there will be options to subscribe a 4G service. The 4G Internet will be obtained through the cellular modems within a smartphone. This cellular system allows Internet access directly from a cell tower that provides phone coverage (Comer 2018).

There are three types of cellular modems: built into phone, portable cellular cards and cellular router. Cellular cards are better known as air cards that may come in a USB shaped or square box with a screen. It can be used by directly tethering the device to laptops or creating hotspot for smartphone users. On the other hand, a cellular router or also known as LTE Router is different to a traditional router where it does not require cable and instead require SIM card with cellular service subscription to provide Internet access, which is shown in Fig. 4 (Hossain et al. 2014).

For rural areas within the coverage of a cell tower, these devices and method of connection will be enough to connect to the Internet. It allows travellers to have easy access to Internet wherever they go as long as there is a cellular coverage. However, for areas where even phone lines do not reach especially in deep rural villages which spans throughout Malaysia, these devices would be inadequate to

Fig. 4 Shows air card device (left) and cellular router (right)

solve the digital divide. While it is true that more towers are being built and upgraded, there will still be limit to its outreach especially in the dense forest region. The clear disadvantage of this network is its dependency to be within a short distance to a communication tower.

3.4 Broadband over power lines

Broadband over Power Lines (BPL) is a method of Power Line Communication (PLC) that allow high speed data transmission to rural areas using existing electrical lines as the main transmission medium. This method was developed to extend internet coverage to rural areas where there are no broadband infrastructures nor mobile internet service provider available. There were generally three types of BPL: *Access BPL, In-Home BPL and Hybrid BPL.* A hybrid approach was to combine Access BPL and serve the network through a wireless transmission media such as WiFi, which is shown in Fig. 5 (Failed 2009).

Although the concept seems sounds but deployments across the world states otherwise. BPL was deployed in many countries (Failed 2009) until they all stop by 2012 following the IBEC cease in operation (Failed 2009). The cease was also due to the report released by NATO that widespread deployment of BPL may cause detrimental effect upon military HF radio communication (Warthman 2015). In December 2017, AT&T in an attempt to revive BPL, released a news of field testing of a new BPL technology through Project AirGig (Shibata 2009). The technology introduced a unique approach to its predecessor by using millimetre wave signals that moves along the surface of power lines instead of using power line communication (PLC) over AC/DC lines. It is worth noted that the millimetre waves are the same technology used in the upcoming 5G network. They claimed that the technology has potential to provide data rates over 1 Gbps although,

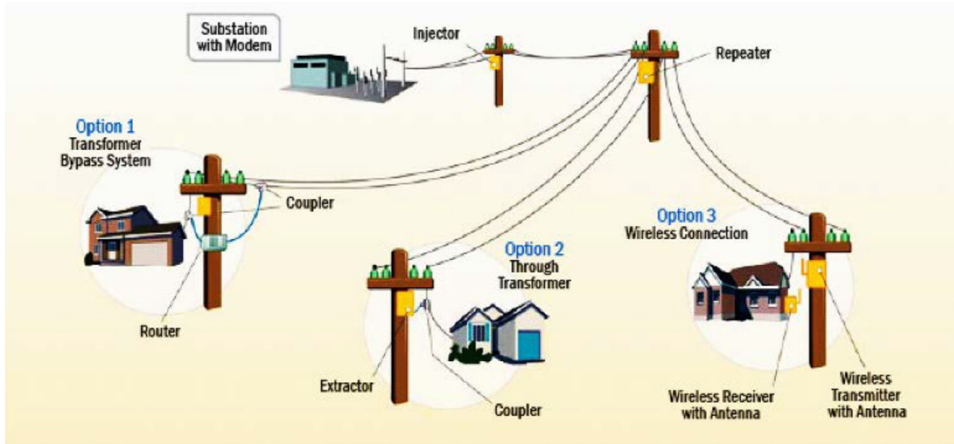

Fig. 5 Shows the different BPL connection types (Shibata 2009)

one year later, no report has been made yet of the said field test.

BPL was originally invented with this contribution in mind; to reach rural places without the need to erect a costly infrastructure and instead, built on top of existing infrastructures like the electric pole. However, unless AT&T is able to solve certain issues like radio interference, performance and range of coverage along with the pilot study to prove the viability of the new BPL, it will not show up again anytime soon.

3.5 Balloon mesh network

Balloon Mesh Network (BMN) is a type of ad-hoc network formed using interconnected balloons to achieve a wide area network connection (SkySat^{TM} 2018). Among the examples of application of BMN can be found in studies such as disaster relief proposal by Shibata et al. (SkySat^{TM} 2018) and giant companies' initiatives in providing rural internet like Google's Project Loon and Data Space Inc SkySat (Hampel 2016).

Loon is a network of stratospheric balloons designed to bring Internet connectivity to under-served regions in the world. The balloons travel approximately 20 km from the ground. Similar to how a normal internet connection works, the data transmitted will hop onto balloons (in terrestrial condition, data hops between servers and communication towers) to link between the affected population, ground station and local internet provider (New Zealand pilot test 2018).

The pilot test for Project Loon started in 2013, South Islands, New Zealand (Tung 2014) which is shown in Fig. 6. After the success of the pilot test, the team moved on to conduct LTE Experiment in Campo Maior, Brazil in the following year (Oh et al. 2016). In 2016, the test in Sri Lanka was halted when the project met a legal issue whereby Google was not authorized to use the same radio frequency as Sri Lanka's public broadcasters according to Geneva-based International Telecommunications Union (ITU). Last year, the balloons were sent up to the sky again to provide internet connectivity to provide disaster relief in Puerto Rico after being struck by Hurricane Maria and Peru after being struck by extreme rains and flooding, gaining popularity once again. Finally, in recent months, there have been talks about collaborative efforts between Google and Kenya government to improve the internet connectivity in Africa. The first commercial deployment of the balloons is expected to be set in 2019 (Oh et al. 2016).

Since neither Space Data nor Google reveals the cost of deployments and maintenance of the technology, there is no guarantee that the rural population would be able to afford the technology. It could be pricier, cheaper or even no difference than a cable-based network like FTTX. Furthermore, for mountainous and forest covered regions, it would be difficult to set a landing point. Therefore, it is a good option for widespread ground like Central Africa and rural America.

3.6 Television white space

Television White Space (TVWS) refers to the unused frequency initially set for TV broadcasts for purposes like buffering and avoiding interference. In recent years, digital TV with higher spectrum efficiency is preferred over the analog TV and thus cleared more spectrum available for TVWS (Masonta 2015). Due to it being within the very-high-frequency (VHF) and ultra-high-frequency (UHF) bands, TVWS can propagate at a very long distance and has better penetration through obstacles. Having an especially long distance makes TVWS a possible option to provide Internet access to rural population in the effort to bridge the digital divide. Additionally, the penetration properties set TVWS up the rank for machine-to-machine (M2M) applications in dense areas like smart city.

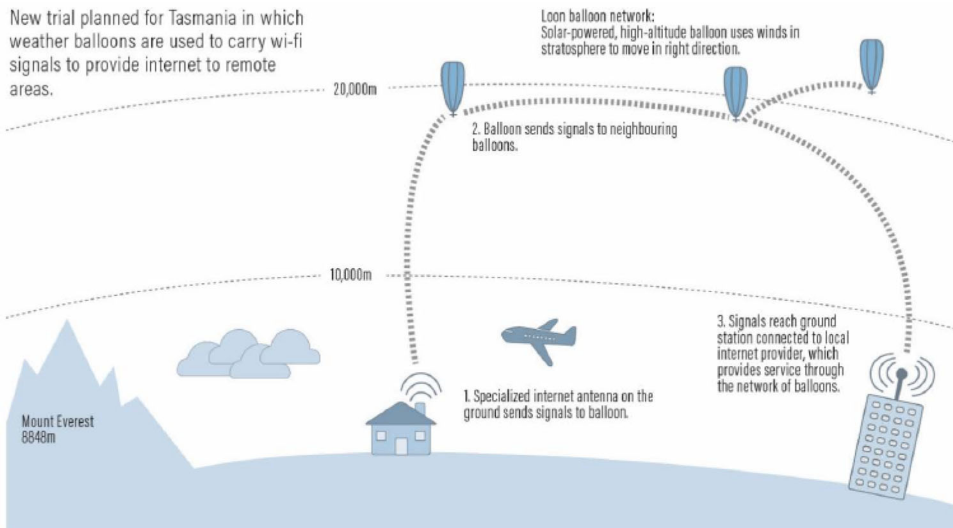

Fig. 6 Shows how transmission happens in Project Loon (Tung 2014)

TVWS provides Internet through a number of steps as explained by Carlson Wireless, which is shown in Fig. 7 (Masonta 2015). It works by connecting to a white space device (WSD) to a TVWS database to detect available channels in the region for its usage. The WSD then get authenticated from the database and request available channels in the region. The device then uses the found list of channels to establish wireless broadband network.

In 2007, to understand the most suitable technology to pair with TVWS, the FCC conducted the first experiment but the results yield was not accurate enough. After being revised many times, the FCC finally released the Memorandum Opinion and Order in 2010 that noted the use of White Space Database (WSDB) as the main method to determine vacant channels to use for TVWS deployment (Masonta 2015). As of 2014, the US, UK, Singapore and New Zealand had released their regulatory framework for TVWS (Khan and Barman 2018). Over the following year, multiple trials were conducted to analyse the performance of TVWS at several places in Africa such as the Cape Town Trial and Limpopo Trial (Khan and Barman 2018). On the other hand, TVWS applications may have interference with some other electronic devices that uses adjacent frequencies such as the wireless microphones (Rouse 2017).

So far, TVWS is the most promising alternative approach to serve the Internet to rural areas. It promises the far-reach and high speed but as it is still not in production mode, it is concerned to share the downfall as WiMax (802.16). Moreover, in recent publication, it was revealed that Malaysia has not started joining the movement and only shows an interest to adopt this technology (Rouse 2017). With the current practice would be illegal, as it uses currently occupied spectrum, this technology is deemed not currently suitable for Malaysia.

3.7 Low powered wide area network

Low Powered Wide Area Network (LPWAN) is a network created for the Internet of Things (IoT). LPWAN can cover an area so large and it varies from 2KM up to 1000KM and accommodate packet sizes from 10 to 1000 bytes at a maximum of 200Kbps (Ali et al. 2017). Although the range and capacity are highly depending on the technology,

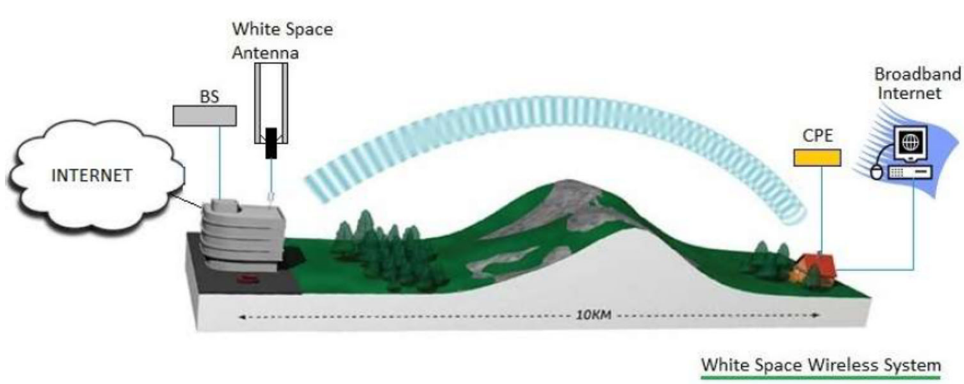

Fig. 7 Shows the concept of delivering Internet through TV

configuration and physical obstructions. It is mainly used for communications between machine-to-machine (M2M); typically, communications between sensors nodes and gateways.

There are many technologies available that can either be used as is or combine together. Among these technologies are LoRa, SigFox, NB-IoT, LTE-M. Each of them uses different frequencies; some licensed, some unlicensed, some proprietary and some are open standards. In the topic of frequencies, there are bound to be interference such as those operating in the 2.4 GHz spectrum; same as WiFi and Bluetooth (Sinha et al. 2017). Each LPWAN has their own strengths and weaknesses. SigFox is an example of a proprietary LPWAN with an uplink packets size is limited to 150 messages of 12 bytes per day and downlink packets size are limited to 4 messages of 8 bytes per day and can reach between 30 and 50 km within line-of-sight. The downside of SigFox is the cost of deployment. To that, many researchers prefer to use LoRa for its open license and flexibility of a self-defined network (Sinha et al. 2017). Other than Sigfox and LoRa, there are other LPWAN technologies like Zigbee, Z-Wave and NB-IoT. The field of IoT is diverse, from a refrigerator and smart meter application to an industrial-sized smart farm, one LPWAN technologies would be more preferred than the other. In many cases, LoRa is seen as the biggest competitor to Sigfox for industrial applications of IoT but in smaller scale for personal and public projects, NB-IoT seems a better choice overall (Ray 2016). In LPWAN, not only there are many network need to be considered but also the underlying protocols. It is often confused that only the higher-level protocols are necessary. A survey on the protocols in an LPWAN technology shows multiple layers from the higher level to the lower ones. The transmission protocols involved at higher level to connect to gateway and the server includes Hyper Text Transmission Protocol (HTTP), Messaging Queue Text Telemetry (MQTT), Constrained Application Protocol (CoAP) and AMQP while lower level protocols at each sensor nodes may use communication protocols such as UART, SPI and I2C to communicate between nodes and/or sensors, which is shown in Fig. 8 (Chekima et al. 2015).

The nature of the IoT which operates within bytes and the maximum of three kilobytes sensor data (Chekima et al. 2015), the adoption of this technology is suitable to certain applications within agriculture industry. However, it is wrong to totally brush aside the wide coverage this technology has to offer as it can be mixed and match with other technologies to create a better pair.

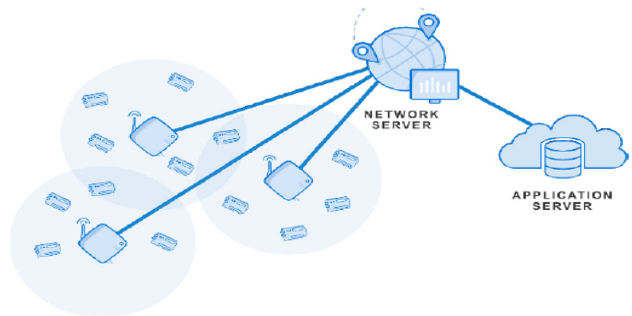

Fig. 8 Shows the sensor nodes and gateway connections to in IoT (Chekima et al. 2015)

3.8 Vehicular ad-hoc network

Vehicular Ad Hoc Networks (VANETs) is an idea of spontaneous connection between vehicles that provides Internet connectivity. Figure 9 shows the application of VANET in ITS. A typical end to end connection is made through vehicle to vehicle (V2V), vehicle to infrastructure (V2I) and hybrid architecture (Cunha et al. 2016). The emergence of this vehicular networks is motivated by digitalization of movements in urban areas. These vehicular networks aim to promote safety and traffic efficiency along with providing a futuristic vehicle designs which incorporates infotainment, driving assistance and urban sensing which ultimately can be translated as Intelligent Transportation System (ITS) (Jain et al. 2004).

VANET is a special case of Mobile Ad-hoc Networks (MANETs) where vehicles are equipped with wireless and processing capabilities to create a spontaneous network between vehicles and infrastructures. The V2V scheme in VANET allows communication even in the absence of infrastructure such as road side units and base stations (Cunha et al. 2016; Jain et al. 2004). However, when a long

Fig. 9 Shows the application of VANET in an ITS (Cunha et al. 2016)

distance is involved, and low traffic level, an end-to-end connection may not be feasible to achieve.

3.9 Delay/Disruption tolerant network

DTN is unlike modern network architecture that is able to withstand intermittent connectivity with the opposite characteristic of the TCP/IP architecture. It was designed to accept challenged or intermittent network conditions that are characterized by higher level of latency, bandwidth limitations, error probability, node longevity or path instability (Suresh et al. 2021b). The DTN architecture was firstly proposed as based on a n abstraction of message switching that each message aggregates are known as bundles. These bundles will be handled by bundle routers or DTN gateways. The idea of handling the unstable path and frequent de-linked path, many routing algorithms were proposed (Suresh et al. 2021b; Burleigh 2007). DTN works with a store-and-forward mechanism through the use of the bundle protocol in DTN gateways (Krishnan et al. 2007). Among the implementation of DTN systems are the Interplanetary Overlay Network (ION-DTN) (Zhang et al. 2011), SPINDLE (Warthman 2015) and DTN2 (Guo et al. 2007).

Among the technologies found, this technology fits the requirement to develop IT sector in rural and deep rural regions in Malaysia (Fig. 10). While some implementation was done in Africa and South India through Kiosknet/Vlink (Anon 2019a) and Wizzy digital courier (Anon 2019a), the results were unclear whether these technologies succeeded at solving the digital divide in the respective regions. Although it receives many sceptical views (Anon 2019a), it is clear that with this technology, even the most remote places in Malaysia can be reached and establish communications with DTN. This however require a highly supporting community (Anon 2019a) from DTNRG, developer and rural community. This however require a highly supporting community (Anon 2019a) from DTNRG, developer and rural community. Table 1 shows the comparison of each alternative technologies and the reason for its suitability and unsuitability for IT sector development in Malaysia.

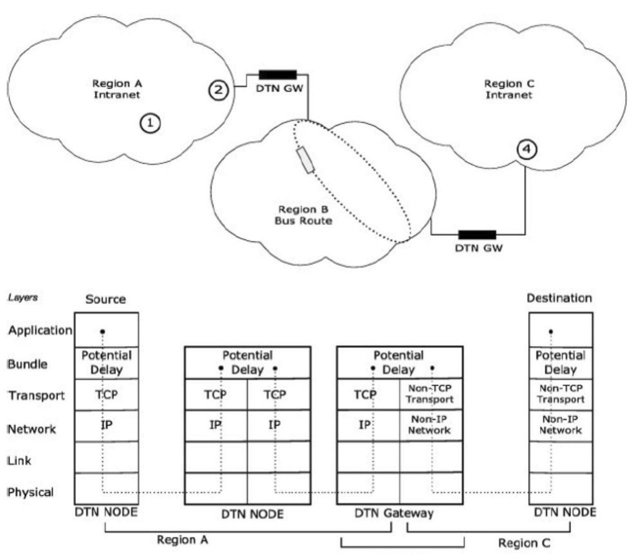

Fig. 10 Illustrate the workings of DTN and the placement of the added bundle protocol in DTN (Burleigh 2015)

3.9.1 Discussion

Among the options discussed above, some are creating an end-to-end route via ad-hoc networks; while some are creating a direct link and others are acting as a temporary router for edge computing devices to connect to. However, there is an interesting concept that embraces the missing link in an end-to-end route—Delay Tolerant Network. Based on the literature and technological review conducted, the four most convincing technologies are listed out with the exception of TVWS due to it not being adopted by Malaysia.

3.9.2 Satellite network

This option is the easiest and works out-of-the-box. However, this is not a viable solution for uneconomic rural areas. Countries like Greenland and Falkland Islands may be able to afford this solution but for landlocked regions with low income per capita, they would not be able to afford it.

3.9.3 Broadband over power line

As proved in between 1990 to 2010, the solution is not able to extend to areas without electric poles. For areas that are separated by water and mountains and those that rely purely on alternative like generator for electricity, this solution will not be able to reach these rural communities. Additionally, this option would not pass policy makers unless the radio interference issue will be solved with the newest research done by AT&T; and even then, it would take years before the technology can be matured for use once again.

3.9.4 Delay tolerant network

Although not much implemented in the real world apart for some experimental studies, this solution may be what the low-income rural communities may need; as long as they have a link from the community to the urban area. This solution however would require further studies and

Table 1 Shows the comparison of each alternative technologies and the reason for its suitability and unsuitability for IT sector development in Malaysia

Alternative		Note
Dial-up Access	✘	Not offered anymore/slow
Balloon Mesh Network	✘	Spectrum regulation issue High cost of implementation Can be political issue
Low-Power Wide Area Network	✘	Too small data packets not suitable Internet application
Vehicular Ad-hoc Network	✘	Not enough traffic to form an end-to-end connection
Satellite Network	✘	Too expensive for most villagers
Broadband over Power Line	?	Considered only if the changes by AT&T proved successful
TV Whitespace	?	Considered if the country adopts the technology
Disruption/Delay Tolerant Network	✔	The cost is much more affordable for low-income rural people

experiments before it can be proven to work. Once that's a done deal, a tight integration effort between investors, researchers and rural communities will still be required until the technology stabilizes. This may require a very long time.

Network types that depends on radio wave such as the LPWAN is not suitable; after all the size of packets that are transmitted over are very small in size. TV Whitespace on the other hand shows increasing popularity in research in recent years; though specification like bit rate and maximum packet size are not officially stated anywhere yet and there are debates against what certain article claim against what the users see regarding the technology. Additionally, it uses an unlicensed spectrum which may or may not have regulations in certain countries. Issues may occur if not developed or handled following a certain protocol, especially in Malaysia where these technologies may be in the grey areas and therefore, these options are not considered and the problem that may arise would be hard to settle.

4 Delay/Disruption tolerant network

A DTN is a network of smaller networks that support interoperability of other networks by accommodating long disruptions and delays between and within the networks. The idea of the DTN is different to a traditional network where it can accommodate intermittent connectivity, long delay, highly asymmetric data rates and high error rates. Due to these characteristics, it was originally developed for interplanetary use cases but is applicable to Earth use cases too (Anon 2019a). Among the many said use cases on Earth includes medical use cases (Anon 2019a), militaristic use cases, commercial (Athanasios et al. 2011) and data-centric as well as peer-to-peer applications (Athanasios et al. 2011). While the previous section has briefly introduced DTN as a whole, this section will provide in-depth view of the architecture.

4.1 The bundle protocol

A quick search from google yields results from Techopedia noting that the Bundle Protocol being an experimental protocol released in 2007 (RFC 5050) (Scott 2007) and were produced by the Internet Research Task Force (IRTF) DTN Research Group (DTNRG) and represents the consensus of active contributors (Scott 2007). The bundle protocol is the most important part of the DTN architecture. The bundle protocol provides the key functions such as the custody transfer, return receipt, bundle forwarding, delivery to the application, priority delivery, congestion and flow control, fragmentation and reassembly. It is worth noted that the lower layers of a DTN are designed to handle heterogeneous protocol layers and therefore, it does not have to stick to one type of protocol stacks. This enables each forwarding node to use different transmission medium at different locations. Figure 11 Shows the comparison between a traditional Internet protocol stack and a DTN protocol stack.

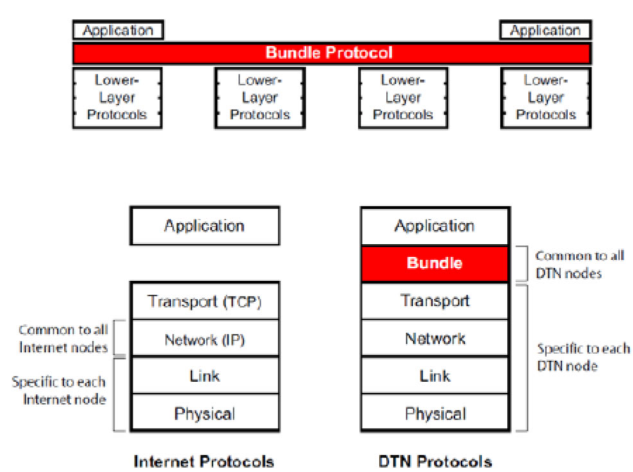

Fig. 11 Shows the comparison between a traditional Internet protocol stack and a DTN protocol stack

4.2 Bundle security protocol

Due to the nature of DTN, the network is not conversational where in traditional network, the source and destination will send a proper handshake to establish an agreement before data transmission begins and in DTN, this can never be achieved due to DTN unable to accommodate many round-trip acknowledgement messages like in TCP (Scott 2007). Therefore, the security is instead implemented in the bundle protocol during custody transfer. This mechanism is implemented in the Bundle Security Protocol (BSP) where there are four possible security measures that can be setup:

- **Bundle Authentication Block** which authenticates the integrity of the node through the header.
- **Payload Integrity Block** which verifies the signer of the payload.
- **Payload Confidentiality Block** which encrypts the bundle payload.
- **Extension Security Block** which provides security for non-payload blocks.

4.3 Significant DTN development in chronological order

In 2002, Dr Kevin Fall began adapting the Interplanetary Network (IPN) with the intention to adapt it to work on terrestrial network on Earth. This was the first appearance of DTN in research (Dias et al. 2011). It is further explained in a thesis of the difference between delay-tolerant network and disruption-tolerant network, that the "delay" was a portion of "disruption" tolerant network which covers the architecture as a whole. The idea of the delay was more applicable to the space environment as in the IPN architecture and the disruption was about the intermittent connectivity and transmission limitation and other challenges in the remote and disaster-stricken regions on Earth (Cerf et al. 2007).

The research continued on and officially received protocol standards in 2007 and 2009 specifically the RFC 5050 (Symington et al. 2011), RFC 4838 (Anon 2016) and RFC 6257 (Anon 2019b). Since then, many applications and frameworks were created such as DTN2, SPINDLE, PRoPHET and the latest in development, the ION-DTN which is currently developed by Advanced Exploration Systems (NASA). In 2015, NASA first demonstrated the capability of DTN by sending selfie to the ISS from Earth (Anon 2019b). In 2016, NASA established the first DTN service within the ISS as the Solar System Internet Technology (Spyropoulos et al. 2010). Two years later, NASA released a news on their latest successful mission in Antarctica to demonstrate the Internet-like communication where the communication capability is limited with no end-to-end connection available (Zeng et al. 2012). With the current advancement of DTN there is little doubt that DTN will fail for terrestrial networks application.

5 Recent and related literature's

Many of the literatures existing in IEEE Xplore, archivX, and other research databases focuses on the routing algorithms, surveys of algorithms, different protocols utilization in bundle layers and usage of DTN in space through Interplanetary Networks. Below articles from this category helps to clarify the method of transmission from one DTN forwarding node to another. These articles made it very clear what routing algorithms are available which will differ in performance according to the environment the DTN network is set-up. From these articles, it is also clear that DTN can be mix-and-matched with other technologies like VANET.

6 Algorithms

No	Articles	Year
Burleigh 2007)	Routing in a Delay Tolerant Network	2004
Krishnan et al. 2007)	Controlling the Mobility of Multiple Data Transport Ferries in a DTN	2005
Zhang et al. 2011)	DTLSR—Delay Tolerant Routing for Developing Regions	2007
Ayub et al. 2013)	Routing for disruption tolerant networks—taxonomy and design	2010
Amendola et al. 2014)	Directional routing and scheduling for green vehicular delay tolerant networks	2013
Salvador et al. 2016)	Threshold based locking routing strategy for delay tolerant network	2013
Sato 2016)	Efficient Neighbor Discovery in RFID based devices over resource-constrained DTN networks	2014
Wong 2017)	Hierarchy-based monitoring of Vehicular Delay-Tolerant Networks	2016
Zhu et al. 2009)	Hybrid Routing Scheme Combining with Geo-Routing and DTN in VANET	2016
Paula et al. 2011)	Reliable multicast disruption tolerant networking Conceptual implementation using message ferry	2017

6.1 Security

The security counter part of DTN architecture works differently from the traditional network where due to the nature to be less conversational, a three-way handshake and cannot be made. Rather, the security is applied in the bundle protocol following the RFC 6257 standard where the least security settings that must be applied is the Bundle Authentication Block where the incoming bundle will get authenticated to decide whether to accept or drop the bundle to prevent attacks such as DDOS Attack.

No	Articles	Year
Symington et al. 2011)	RFC 5050 Bundle Protocol Specification	2007
Anon 2016)	RFC 4838 Delay Network Architecture	2007
Amla et al. 2018)	SMART A Secure Multilayer Credit-Based Incentive Scheme for Delay-Tolerant Networks	2009
Anon 2019b)	RFC 6257 Bundle Security Protocol Specification	2011
Wood et al. 2009)	An embedded VDTN testbed for the evaluation of vehicular safety systems	2011
Isento et al. 2011)	Improving Security and Performance Parameter using Social Skeleton in heterogeneous VDTN	2018

6.2 Applications

The security counter part of DTN architecture works differently from the traditional network where due to the nature to be less conversational, a three-way handshake and cannot be made. Rather, the security is applied in the bundle protocol following the RFC 6257 standard where the least security settings that must be applied is the Bundle Authentication Block where the incoming bundle will get authenticated to decide whether to accept or drop the bundle to prevent attacks such as DDOS Attack.

No	Articles	Year
Dias et al. 2011)	Moving data in DTNs with HTTP and MIME	2009
Hanawa and H, 2014)	FTP@VDTN—A file transfer application for Vehicular Delay-Tolerant Networks	2011
Krishnan et al. 2007)	WWW@VDTN—A Web browsing application for Vehicular Delay-Tolerant Networks	2011
Guo et al. 2007)	An implementation of DTN testbed based on DTN2	2011
Alaoui et al. 2015)	DTN Data Message Transmission by Inter-vehicle Communication with Help of Road Map and Statistical Traffic Information in VANET	2014
Sun et al. 2011)	Efficient Packet Forwarding Approach Using Public Vehicles	2015
Paul et al. 2015)	The Interplanetary Internet Implemented on the GENI Testbed	2015

6.3 Literature survey on DTN

From the first appearance of DTN, a survey was conducted to observe its use cases that are clear to be used for both Interplanetary Networks and resource-restrained Terrestrial Network. Following the possible applications, further survey includes the protocols, testing, performances, challenges and future applications of DTN.

No	Articles	Year
Suresh et al. 2021b)	A delay tolerant network architecture for challenged internets	2003
Burleigh 2007)	Routing protocols in delay tolerant networks A comparative survey	2008
Cerf et al. 2007)	Delay Tolerant Networks Protocol and Applications	2011
Li et al. 2015)	On Delay-Tolerant Networking and Its Application	2012
Kishor et al. 2021)	Challenges in designing testbed for evaluating delay-tolerant hybrid networks	2015
Chakraborty et al. 2014)	Delay-tolerant network protocol testing and evaluation	2015
Abdelkader et al. (2016)	A performance comparison of delay-tolerant network routing protocols	2016
Unnikrishnan et al. (2016)	Delay Tolerant Network for Space	2016

7 Conclusion

The literature and technological review revealed many alternative options already created throughout the years. Ranging from the most commonly known satellite networks to the recently emerging television whitespace network, each have their own specific use cases, advantages and disadvantages. While some technologies died out throughout the years, some revive through the combining the architecture with one another such as can be seen in VANET and DTN. In the end many of the technologies are deemed unsuitable due to the characteristics of each network architecture. The only one that prevails among them is the Disruption/Delay Tolerant Network (DTN). Since the first appearance of DTN, many researches have been carried out to improve the overall architecture and performances of DTN. Along the way, there have been multiple implementations and revisions created for DTN such as DTN2, SPINDLE and ION-DTN. These implementations have helped DTN to be a matured architecture now implemented by NASA to perform tests and in the future, space mission. It is also decided that to accommodate the resource-strict requirements of IT development in the rural sector of Malaysia, DTN is the most suitable choice for adoption. In future, further literature reviews will be conducted to find the best way to implement a full DTN system.

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Declarations

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

Human and animal rights The manuscript has not been submitted to more than one journal for simultaneous consideration. The manuscript has not been published previously. The Research not involved human participants and/or animals.

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