A REVIEW OF DELAY TOLERANT NETWORK TECHNOLOGY 2016

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Abstract

Delay Tolerant Network Architecture (DTN) aims to provide connectivity in scenarios where the internet's TCP/IP protocol stack is partially or wholly ineffective due to lack of infrastructure, mobility or other similar factors which prevent the establishment of the end to end link needed for TCP/IP.

Work in the DTN field has largely focused on replacing TCP/IP in a technical sense, that is replacing TCP/IP's ability to pass a message from a source to a destination, however the problem has not been widely examined from the human perspective, that of the end user. From the end user's perspective, the internet provides not only the ability to pass messages, but also close to real time access to data and information.

An effective DTN would need to provide end users with the best possible approximation of both the internet's ability to pass messages and gain timely access to data.

It seems likely that DTN protocols will need to be use case or application specific and there will not be a single universal solution or protocol to replace TCP/IP in the DTN space. As a result, the standardisation of DTN technology needed to make it deployable out of the box as a commodity technology is likely to be difficult to achieve. Perhaps the most viable solution would be to have a standardised set of protocol interfaces, which would allow a DTN to be deployed with a selection the available protocols which best meet the needs of its specific use case by plugging the chosen protocols into the relevant protocol interfaces.

Such a solution could well enable a DTN to deployed out of the box in much the same way as a TCP/IP network can be deployed today.

The ability to rapidly deploy a DTN in this manner could well have a dramatic impact on rural and remote communities which don't have access to regular internet infrastructure, and could significantly improve the ability of emergency services and aid organisation to better perform their work in emergency and disaster areas where there is either no existing infrastructure or the infrastructure has been destroyed or rendered inoperable.

Perhaps the best way to move DTN toward this end goal at this point is to raise awareness of the data availability gap and the need for protocol interfaces, thus catalysing the conversation on this topic in the research community, and providing some baseline protocols and interfaces upon which the research community can build toward a more complete solution.

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1. Introduction – Background of Delay Tolerant Network (DTN)

Vint Cerf, a pioneer of the internet with his work on TCP in the 1970s started working on the idea of an interplanetary internet (IPN) in 1997 (McMahon & Farrell, 2009).

The early research into the IPN highlighted several challenges, in particular the large latency caused by extreme distances. It was in this period of research that the idea of designing networks to be tolerant of disruption and delay first arose in literature (McMahon & Farrell, 2009)

The key conceptual difference between the internet and the IPN was that:

"Whereas the Earth's Internet was basically conceived as a 'network of connected networks,' the IPN was thought of as a 'network of disconnected Internets' connected through a system of gateways" (McMahon & Farrell, 2009)

This work quickly led to the investigation of how usefully the new IPN protocols could be applied to other scenarios where networks operated under challenged conditions. In 2003 Kevin Fall published a landmark paper proposing a delay-tolerant networking architecture (DTN) to deal with the many challenges faced in extreme and challenged environments such as high latency, low data rate, disconnection and long queuing times (Fall, 2003).

Fall's primary contention in establishing a need for DTN is that in challenged environments the internet's ubiquitous TCP/IP protocol could not properly serve the challenged network because some of the fundamental assumptions of TCP/IP (particularly that an end to end path exists between source and destination) were not met, or at least could not be guaranteed(Fall, 2003).

In his paper, Fall (Fall, 2003) proposed several scenarios in which TCP/IP may not serve a network ideally, and where a DTN could be useful, including:

Mobile Networks: These are networks in which nodes, due to their mobility or varying signal strength, may move in and out of range of other nodes, causing frequent and prolonged disruptions to connectivity.
Exotic Media: This refers to non-standard or unusual physical network media; for example acoustic links in water, which can impact performance through limitations such as range, data rates and reliability.
Military Applications: In such applications, operations are often occurring in hostile environments, where the combination of mobility, intentional enemy interference and operation security concerns all impact network performance, reliability and connectivity.
Sensor Networks: Which are characterized by concerns such as limited end-node power, low duty cycles, low processing power and memory, and potentially operating in extremely large networks with thousands or even millions of sensors in the network.

Falls (Fall, 2003) DTN architecture introduced several core concepts to the DTN space several of which were taken from an examination of snail mail and email as delay tolerant forms of communication. Some of the concepts taken from mail and email were asynchronous message based operation, flexible naming protocols, differing classes of messages and message custody.

2. DTN Vs. Mobile Ad-Hoc Network (MANET) Distinction

2.1 What is MANET?

A Mobile Ad-Hoc Network (MANET) is an ad-hoc (and peer to peer) wireless network in which 'peer' devices connect to each other directly in an arbitrary and opportunistic manor, and which (unlike an infrastructure based WLAN), does not have access to a central controlling base station that directs and controls contention for access to the network and acts as a gateway for routing purposes (Toh, 1996) (Royer & Toh, 1999).

The idea of ad-hoc wireless networks was developed well before that of DTN. The earliest wireless routing protocol capable of supporting ad-hoc or infrastructure-less wireless networks was the DARPA Packet Radio Network (PRNET) developed in the 1970s (Kahn, et al., 1978) (Toh, 1996) (Jubin & Tornow, 1987).

PRNET continued to be the standard in the field for over a decade, and Jublin and Tornow (Jubin & Tornow, 1987) described the state of the technology after running a network based on the PRNET protocols for 10 years.

Some of the key points they use to describe PRNET are:

- 'Self-configuring upon network initialization',
- Reconfigures automatically upon gaining or losing a node,
- Intended to run without human control / management,
- Self discovers connectivity between nodes,
- 'Organises routing strategies dynamically on the basis of this connectivity'.

(Jubin & Tornow, 1987)

They also noted that a unique feature of PRNET is that a change in topology may have no discernable effect on the end user's communication.

In the 1990's the volume of research into ad-hoc wireless networks escalated significantly, largely due to the growing ability of users to connect directly amongst themselves. That ability to connect arose from the introduction and rapid-proliferation or off-the-shelf wireless technologies with networking capabilities such as Wi-Fi and Bluetooth (Conti & Giordano, 2014).

During the 1990's the concept of a MANET or mobile ad-hoc network became the leading paradigm in the ad-hoc networking space and in October 1998 the IETF MANET working group was established to take the lead in this field (Corson & Macker, 1998).

The IEFT MANET working group assumed that the MANET space needed a single, non-application specific solution modelled on the internet.

As a result of this assumption, the IEFT MANET working group focused on the development of IP centric, general purpose, 'pure' MANET technology. These 'general purpose' networks were not designed to support any specific functionality but rather intended to support any legacy TCP/IP application and were considered 'pure' because they were built on the assumption of a total lack of network infrastructure (Basagni, et al., 2004).

This assumption also led to a lot of work being directed at adapting, extending or enhancing TCP/IP and other layers in the network stack to meet MANET requirements, and a large number of alternate protocol proposals arose as it became evident that the protocols used for the internet were not suitable in the highly unstable topologies typical of MANET. Each of the proposed protocols had strengths and weaknesses, and many were suitable for certain MANET use cases or applications, however no solution proved universally suitable to all contexts (Conti & Giordano, 2014).

Out of the work of the IEFT MANET working group (and subsequent research) a new paradigm arose in ad-hoc networking, learning from the problems of the past and promising to avoid some of the mistakes of IEFT MANET. This paradigm included things such as the application specificity of MANET protocols as well as the reduction of complexity and the increased realism of testing in MANET research.(Conti & Giordano, 2014).

2.2 DTN Vs MANET - Key Distinction

As discussed later in this paper, the DTN Vs MANET distinction is often blurred in the literature. On a purely conceptual level, the key conceptual difference between MANET and DTN's would seem to be that when a MANET node becomes disconnected from the MANET, perhaps due to mobility, poor signal strength or other factors, it is considered to have left the network. This is in contrast to DTN where a node is considered part of the network even when there is no immediate connection or path to it.

3. Current state of DTN technology.

Since the work of Fall in 2003, there has been a significant amount of interest in DTN. A large portion of the research appears to have been technically focused, and within that category there have been two main focuses.

3.1 Developing TCP/IP alternatives

There has been a significant amount of focus on developing routing, forwarding, and message encoding protocols (Dai, et al., 2010) and this work can be largely viewed as an attempt at replacing TCP/IP in the DTN.

The focus on replacing TCP/IP is not surprising for two reasons, both of which can be traced back to Fall's 2003 work.

Firstly, Fall's primary justification for needing the develop DTN technology is that the TCP/IP stack is ineffective in challenged environments because those environments don't meet many of the assumptions which are made by TCP/IP. Secondly, Fall identifies path selection and scheduling as the major area in which future work is required (Fall, 2003). Given these as a starting point it is understandable that much of the work that has followed is focused on solving these problems and finding a replacement for TCP/IP for DTN.

One of the primary problems that this routing related work tries to solve is that of increasing the probability of finding a path to the destination node where there may be extremely limited information available as to the location of the destination node (Balasubramanian, et al., 2007).

3.1.1 The Epidemic Protocol

The first routing protocol to be considered for use in DTN actually predates Fall's 2003 work.

Vahdat & Becker (Vahdat & Becker, 2000) proposed the Epidemic routing protocol three years before Falls 2003 paper. Vahdat & Becker proposed Epidemic to solve the problems of partially connected (or challenged) ad hoc networks and in doing so somewhat predicted the place that DTN would soon come to fill. The Epidemic protocol, is a packet replication based protocol which in simple terms, distributes messages to all connected portions of the Ad-Hoc network, and relies on the movement of nodes to come into contact and create a connection with nodes in other connected portions of the network enabling the eventual passing on of the message to the destination node.

Some subsequent work in DTN routing and related protocols extends the Epidemic protocol, for example (Fatima & Wahidabanu, 2011) looks at integrating buffer management with the Epidemic protocol. This work attempts enhance the performance of real time or delay sensitive applications within a DTN by prioritising buffered traffic in networks where there is limited bandwidth or transmission opportunity.

Much of the subsequent work in DTN routing and related protocols
uses Epidemic as at least one of the baselines against which the later work is evaluated (Balasubramanian, et al., 2007) (Dai, et al., 2010) (Dvir & Vasilakos, 2010) (Spyropoulos, et al., 2010) (Singh, et al., 2013) (Albini, et al., 2014) (Wang , et al., 2016) (Zhao, et al., 2006) (Haller, 2014).

3.1.2 Post-Epidemic

Several mechanisms have been examined in the attempt to solve the routing and forwarding problems and optimize the process. The key distinctions in the field are:

3.1.2.1 Message retention

- Forwarding
  A forwarding approach passes a copy of the message to the next node and does not retain a copy of the message itself after it is passed (Spyropoulos, et al., 2010).

- Replication
  A replication approach passes a copy of the message to the next node but retains a copy itself after the message is passed (Spyropoulos, et al., 2010).

3.1.2.2 Message passing decision

- Probabilistic
  A probabilistic approach routes single or small numbers of copies of messages to nodes calculated to have the highest chance of having a viable path to, or coming in contact with the destination node. (Spyropoulos, et al., 2010) the most widely examined of the probabilistic approaches is PRoPHET, but another particularly interesting approach to this is the use of geo-locational history to predict the probability of nodes reaching a destination (Link, et al., 2011).

- Flooding
  A flooding approach passes the message to multiple nodes, in some cases every available node, in an attempt to reach the destination via brute force. (Spyropoulos, et al., 2010)

- Backpressure
  A backpressure approach makes forwarding decisions on a per packet basis taking into consideration the queue size on neighbor nodes, data scheduling on nodes and random walk. Forwarding data in such a way as to attempt to equalize the queue or backpressure across nodes (Dvir & Vasilakos, 2010) (Albini, et al., 2014).

3.1.2.3 Network optimisation

- Resource allocation
  A resource allocation approach seeks to enable the optimisation of the network by taking the resources used into account when making the decision to replicate a message and makes a judgement as to whether the increase in utility generated by replication justifies the network resources used to do so (Balasubramanian, et al., 2007).

- Network coding
  A network coding approach attempts to reduce the number of transmissions required and hence reduce the network overhead by having intermediate nodes examine messages and group or merge messages bound for a common destination (Effros, et al., 2010).

- Source coding
  A source coding approach encodes a message at the source node prior to transmission to achieve specific outcomes which may include things like minimising the size of the data transmitted thus minimising resource demand on a DTN or providing an error correcting mechanism to reconstruct segmented messages in cases where some segments or frames are lost in transmission and only some frames

arrive at the data at the destination node (Dai, et al., 2010) (Albini, et al., 2011).

3.1.4 Recent Work in DTN Protocols

Despite having received a significant amount of attention the TCP/IP replacement problem is not yet solved and is still being actively examined.

In 2011, Albini (Albini, et al., 2011) proposed the Delay Tolerant Transport Protocol (DTTP) which aims to provide reliable end to end communication through the use of Fountain Codes, a form of error correcting source coding, which allows for data loss within the network and removes the need for the destination node to send delivery confirmation.

In 2014, Albini (Albini, et al., 2014) were still working on improving and extending DTTP by proposing a control mechanism to optimise the 'tradeoff between content distribution and the use of network resources'.

As recently as this year, Wang (Wang , et al., 2016) proposed a hybrid solution, the Area Approaching and Spray-and-Wait Routing Scheme (AAaS) which incudes:

- a routing module to deal with the forward and store decisions.
- a region management module which tries to accumulate information about the region the subject node is in, including assessing historical patterns of node movement for future predictive routing use.
- A neighour management module which assesses historical patterns of contact with neightbour nodes, again for future predictive routing use.

At the moment there is no definitive standard solution for the replacement of TCP/IP protocol within a DTN and it seems possible that there may never be a single best solution (Spyropoulos, et al., 2010) but rather a suite of possible solutions which can be peiced together as required to best meet the requirements of specific situations and use cases.

Some good examples of the use case specificity of the work in the field are the work of Singh (Singh, et al., 2013) and Zhu (Zhu, et al., 2008) .

Singh (Singh, et al., 2013) focused on the routing and forwarding problem through the specific criteria of a DTN which requires delivery to multiple destinations and considered the tradeoff between delivery delay and energy consumption as well as analyzed the problem as Markov chain.

Zhu (Zhu, et al., 2008) focused on delay tolerant sensor networks and used a mobility prediction mechanism to optimise the gathering of data through the sensor network.

3.2 Other focuses in DTN Literature

3.2.1 Enhancing DTN performance with Throwboxes

There are many different possible use cases for DTN. For many of these, particularly networks with predominantly mobile nodes, the ability of a DTN to successfully pass a message from a source node to a destination node may be dependant on the number and frequency of contact opportunities between nodes. In some cases contact opportunities between mobile nodes may be predictable (e.g. satelite passes), however in other cases such as human carried mobile devices these contacts will be opportunistic due to random walk (Fall, 2003).

Zhao (Zhao, et al., 2006) introduced the concept of throwboxes: inexpensive devices with micro-processors, storage and wireless interfaces that can be deployed at strategic points within a DTN coverage area and act as relays for mobile nodes which pass through the subject location at different times, thus creating contact opportunities that otherwise would not have occurred.

By increasing the number of nodes within a network, and positioning additional stationary nodes at key high traffic points in the network coverage area, the number of opportunitic contacts can be significantly increased, thereby increasing network throughput, and decreasing latency (Zhao, et al., 2006).

Since 2006 there has emerged a growing body of work relating to the use of throwboxes in a DTN (Banerjee, et al., 2007) (Banerjee, et al., 2010) (Haller, 2014) The two major themes in this field seem to be routing and forwarding protocols specific to throwbox enhanced networks (Zhao, et al., 2006) (Haller, 2014) and energy efficiency and replenishment based on the assumption that throwboxes will not have access to power infrastructure (Banerjee, et al., 2007) (Banerjee, et al., 2010).

3.2.2 Throwboxes and Kiosks as Network Access Points

(Haller, 2014) re-examines the TCP/IP replacement problems by examining routing and forwarding protocols within the throwbox enhanced DTN context, and also interestingly adds a second possible conceptualisation of the role of throwboxes, away from that of increasing contact opportunities to that of providing a network access point.

The concept of network access points in DTN is not new. The concept is central to the kiosks of Daknet, a form of DTN designed for use in developing countries to provide digital communications to outlying villages which lack the infrastructure for more conventional internet access. (Pentland, et al., 2004)

Daknet relies on Wi-Fi and potentially Mobile Ad-Hoc Network connections to a central ‘kiosk’ (in addition to shared PC resources being available at the kiosk itself), to accumulate messages and data requests which are stored at the kiosk. These stored messages are ultimately forwarded, via an opportunistic point to point link with a ‘mobile access point’ (MAP) transported on the regular regional bus service, and are in turn forwarded the to the internet when the MAP reaches a location (and creates a connection) to a relay with the requisite internet access. (Pentland, et al., 2004) Whilst a great example of the kiosk with mechanical backhaul concept, Daknet is not the only work that has been done in this space (Seth, et al., 2006)

Perhaps the key difference between the kiosk concept, and the concept of throwboxes as network access points is the intended permanence of the infrastructure.

Kiosks are framed as a long term and permanent solution which may use for example a PC, be centered in or around an active rural community and it's service is seen as being provided as a business (Pentland, et al., 2004) it would seem reasonable to expect kiosks to have access to regular power supply and maintenance.

Throwboxes are generally framed as smaller, lower cost (and thus probably lower capacity) infrastructure (Zhao, et al., 2006) which may use for example micro-controllers, and is often assumed to have no regular power supply (Banerjee, et al., 2007) (Banerjee, et al., 2010). As such throwboxes may be much more suitable for use in situations where a network needs to be quickly and cheaply established, the infrastructure deployed is viewed as largely disposable and of limited lifespan.

3.2.3 DTN in Emergency and Disaster Scenarios

There has been a significant amount of work aimed at providing communications in emergency and disaster scenarios where normal infrastructure is either non-existent or inoperable. (Dilmaghani & Rao, 2008) (Saha, et al., 2012) (Reina, et al., 2014) (Bhattacharjee, et al., 2015) (Kitada , et al., 2015) (Yamashita & Takami, 2015) (Rosas, et al., 2016)

Much of this work focuses on Ad Hoc networking rather than DTN (Dilmaghani & Rao, 2008) (Saha, et al., 2012) (Reina, et al., 2014) (Rosas, et al., 2016), although as early as 2000 (Vahdat & Becker, 2000) established a need for delay and disruption tolerant networks in emergency scenarios.

Work on the application of DTN to emergency and disaster scenarios can be seen to follow similar themes as the greater body of work in the DTN space, with work focused on routing and forwarding protocols (Yamashita & Takami, 2015), and energy efficiency based on assumptions similar to those in the throwbox stream of research. (Bhattacharjee, et al., 2015)

3.2.4 Vehicular DTN

As with the work on the use of DTN in emergency scenarios, the work on the use of DTN in vehicular specific applications has been largely overshadowed by the work on the use of ad-hoc networking technology in vehicular specific applications (Vehicular Ad-Hoc Network or VANET) (Mehta , et al., 2013) (Nadia, et al., 2012) (Amudhavel, et al., 2015) (Mejri, et al., 2014).

VANET operate under some particular conditions which either do not exist, or are much less pronounced in non-vehicular ad-hoc networks, some of these conditions help whilst others hinder the development of effective VANET technology.

The most significant of the challenges particularly evident in VANET is the dynamic topology and frequent path breaks resulting from the participant nodes moving in and out of range of each other at much higher speeds when mounted on vehicles, particularly when vehicles are moving in opposite directions. (Mehta , et al., 2013)

One significant advantage VANETS have over non-vehicular ad-hoc networks is that vehicle mounted nodes can reasonably be assumed to have access to a power supply, and so power management and replenishment is not a significant concern in VANET.

The highly dynamic topology and frequent path breaks of vehicular networks make them potentially highly suitable for the application of DTN technology and (Fan, et al., 2012) looks specifically at the integration of the two disciplines. The work that has occurred in the vehicular DTN space can also be seen to follow comparable themes to the work in the wider DTN space with work on the TCP adaption or replacement and routing problem (Ishikawa, et al., 2014) (Ishikawa, et al., 2015) including the use of kiosk or throwbox equivalent roadside access points (Ikeda, et al., 2013)

3.3 DTN and MANET Synergies

The blurring of the distinction between DTN and MANET is evident throughout the literature in both disciplines.

There are several attempts in MANET literature to deal with the problem of delay and intermittent or disrupted connectivity in MANETS (Vahdat & Becker, 2000) (Reina, et al., 2014) (Luo, et al., 2015)

DTN implicitly has several networks which are disconnected, and those networks could well be MANET based networks, effectively re-purposing McMahon and Farrell's (McMahon & Farrell, 2009) concept of "network of disconnected Internets" to "network of disconnected MANETs"

There has been some work explicitly aimed at the integration of the two network types (Ott, et al., 2006) and also work aimed at the integration of DTN concepts to specialist ad-hoc network applications such as VANET (Fan, et al., 2012) . Some work simply assumes that such integration is necessary (Fatima & Wahidabanu, 2011)

The DTN-MANET integration concept also arises in several places in literature on the use of both DTN and MANET as quickly deployable infrastructure in emergency and disaster scenarios (Reina, et al., 2014) (Bhattacharjee, et al., 2015) (Kitada , et al., 2015).

This 'pure' MANET based DTN concept is possibly most applicable in the emergency or disaster scenario, or possibly for military use because of the 'pure' networks assumption of the absence of, or destruction of infrastructure, combined with the need to be able to rapidly establish reliable communications to support time sensitive operations.

In most other scenarios such as Daknet, VANET, particularly with road-side access nodes, or the use of MANET to extend existing internet connectivity, there is some level of assumption of the availability of permanent infrastructure and ultimate internet connectivity.

4. Discussion - Gaps in DTN

Since the emergence of DTN, the majority of questions asked and researched in this space have been how best to replace, augment or otherwise emulate the technical function of internet's TCP/IP protocol in ad-hoc or challenged network environments where TCP/IP is wholly or partially un-viable.

The questions that have been asked thus far, have been primarily focused on the passing of messages and movement of data, which intuitively seems to be the key problem as this aligns with the technical role of the TCP/IP protocol which is being emulated.

The question that is not being widely asked in this space is not a technical question but a human question. When we ask what technical role TCP/IP plays on the internet it seems apparent that it is the end to end passing of data, however from an end users perspective the internet's (and so TCP/IP's) ability to pass data, reliably, at very high speed, with low latency also provides the end user with near real time data availability.

When we start to consider the question of what TCP/IP provides to end users, it is apparent that the ability to pass messages is only part of the answer, and that it also provides end users with (close to) real time data availability.

The same limitations that cause TCP/IP to be ineffective in challenged networks, things like disconnection, long queue times, high latency and low data rate, mean that even the highest performing DTN message passing protocols will not be able to reliably provide the data availability functionality to end users that TCP/IP does via the internet.

When considering things from this end user functionality perspective rather than a technical TCP/IP replacement perspective, the question becomes that of how can we best approximate in DTNs the end user functionality provided to the internet by TCP/IP, including both passing of messages and data availability.

The issue is not entirely unconsidered, (Seth, et al., 2006) does consider the ability of Daknet to provide data access to remote villages and whilst it seems unlikely that full 100% real time data availability such as TCP/IP provides will ever be realized in DTN, it also seems that significant improvement could be made in the speed at which selected or key data is available in many cases through the considered examination of the DTN problem from a data availability perspective.

5. Review of Recommended Future Work

In his 2003 work Fall (Fall, 2003) identifies some key issues as focal points for future work. These include:

- Determining the existence and reliability of contacts
- Keep track of the state of messages
- Assigning messages to nodes in an efficient manor
- Determining the most effective transmission order for messages.

Work since 2003 can be seen in many cases to be focused on addressing one or more of these problems in one variation or another, or further developing work already done in addressing these problems.

This pattern can be seen in the future work recommendations of many authors.

In 2007 Balasubramanian (Balasubramanian, et al., 2007) points to the development of a more sophisticated algorithm for estimating delay as a future work to improve the performance of their RAPID protocol.

Through 2010 when Dai (Dai, et al., 2010) identifies the need to implement their protocol in a real environment to get more accurate results and propose the evaluation of the scalability of two different protocols, and Dvir (Dvir & Vasilakos, 2010) proposes the comparison of the results of their routing schema with existing schemes and the incorporation of more realistic movement models.

And more recently Albini (Albini, et al., 2014) identifies a need to test their mechanism in more extreme situations, for example with high message loss rates or in particularly sparse networks. Wang (Wang , et al., 2016) similarly focus for future work is on the development of algorithms to better manage network traffic and routing.

These patterns of recommendations for future work can also be seen in the more specialized sub categories, for example in the throwbox space Haller (Haller, 2014) recommends the deeper investigation of the parameters used for their routing protocol and a related optimisation of the protocol.

In the VANET space, Ikeda (Ikeda, et al., 2013) proposes the extension of their simulation of their subject protocol and situation, which focuses primarily on throughput and delay in roadside access point enhanced VANET, and similarly (Ishikawa, et al., 2015) proposes more extensive simulation of their protocol stack and scenario with a view to optimising their parameters and simulation settings.

6. Conclusion

The first and most apparent conclusion to be reached is the need to extend the paradigm through which DTN technology is being viewed. Until now the work in DTN space has focused on TCP/IP replacement from a technical or routing and message passing lens, this is undoubtedly a critical part of the problem. It is apparent however that this approach only considers part of the problem and it is necessary to also consider not only the passing of messages but the full end user functionality including the provision of data availability, and possible approaches at improving data availability in DTN.

It also seems unlikely that there will be a single standardised solution to the DTN problem, (such as TCP/IP provides for the internet) but rather a need for application specific solutions and perhaps the best approach is to develop a set of standardised interfaces for each key element of a DTN protocol stack, this would allow an individual DTN deployment be pieced together in a mix and match fashion from an extendable toolbox of protocol options to form the best possible solution for a specific use case.

Spyropoulos (Spyropoulos, et al., 2010) laid a foundation for this kind of approach to DTN however this proposed framework may benefit from further examination and extension to include other possible module types, most obviously in this case the inclusion of data availability modules, but also interfaces for throwbox and kiosk module inclusion in DTN.

Finally, it seems evident that there are some strong synergies and overlaps between DTN and Ad Hoc networks such as MANET or VANET. Whilst DTN is not exclusively applicable to ad-hoc networks, it shares some similar underlying assumptions such as a lack of, or need to operate without traditional TCP/IP based network or internet infrastructure.

There will certainly be some specific use cases for which this conclusion may not be applicable, however is would seem that protocols and solutions offered in the DTN space should generally provide consideration to the protocols ability to deal with and interoperate with ad hoc networks as core functionality.

7. Recommendations for Future Work

There are numerous researchers who are pursuing solutions and protocol options in the DTN routing and message passing space.

There is an identified gap in data availability protocol space and also an identified need to extend the work of Spyropoulos (Spyropoulos, et al., 2010), either of which would contribute to DTN technology in an area that is currently under-examined.

With this in mind it is recommended that:

a) a prototype protocol interface specification for DTN data availability modules be developed.
b) an initial 'baseline' data availability module be developed in compliance with the prototype interface specification to provide the data availability space with a baseline equivalent to the epidemic protocol in the routing and message passing space.

8. Where this work will lead

It is not anticipated that this work would directly solve the data availability problem in the DTN space.

By opening the conversation in this space, it is anticipated that more researchers will take an interest and the body of work in this area will expand accordingly, bringing us closer to a viable solution or set of solutions.

In stimulating this expanded conversation and body of work, the provision of a prototype interface protocol (even if ultimately the prototype is discarded) will provide an initial starting point for future work and the catalyst for the continued development of such a protocol and similar protocols for the routing and message passing, and throwbox and kiosk spaces.

This work in interface protocol development may ultimately lead to a viable and universally accepted set of interface protocols in the DTN space, enabling use case specific mix and match DTN networks to be quickly and easily deployed as out of the box solutions in a manner similar to the way TCP/IP networks can be deployed today.

Finally, by providing a baseline data availability protocol, future work in the data availability space will have a baseline against which to measure newly proposed protocols, or alternatively a protocol to build upon and improve.

9. Why it matters

An ability to quickly and easily deploy effective, use case specific DTN infrastructure (that provides a reasonable approximation of the end user functionality provided by the internet), as a standardised, out of the box solution could have significant implications in many scenarios, and often significantly improve the prospects of some of the world's most needful, disadvantaged or unfortunate people.

Ultimately the work proposed in this paper could lead to an ability to:

- Provide digital connectivity to the world's poorest people, narrowing the digital divide.

- Significantly improve the ability of first responders and disaster management agencies to deal with disaster scenarios where there is limited or inoperable communications infrastructure.

- Enable aid and humanitarian agencies to better manage crises in developing countries and areas with poor or no communications infrastructure.

- Perhaps one day (space travel technology permitting) provide a viable interplanetary internet, the conception of which provided the genesis of the DTN concept.

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