Delay Tolerant Networks in Rural Areas

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***Abstract*— This article focuses on the role of delay tolerant networks for providing delay tolerant services to rural areas. DTNs have gained considerable importance as a connectivity solution to rural areas in the past few years. Many projects have been completed and different architectures deployed to test performance of DTNs. Initially in this article, the requirements of rural area DTNs are discussed and then a comparative study of different architectures is presented under the guidelines of these requirements. The DTN architectures discussed in this article have been deployed in Nordic region and in India with slightly different goals. The similarities and differences of these DTNs are discussed in detail. This gives us an insight to the pros and cons of these architectures. A few common problems related to these architectures are identified. At the end, modifications to the current architectures are proposed to increase the efficiency of the network.**

***Index Terms*—Comparative study, Delay tolerant networks, Mechanical Backhaul, Rural areas**

I. Introduction

THE growth of ICT industry and Internet in the past two decades has made a deep impact on almost every aspect of human life. Methods of information distribution, service provision and entertainment delivery have revolutionized in the past few years. With this shift, a common person's dependency on ICT and Internet has increased to a point of necessity.

Even though Internet users have grown at a tremendous rate and are still growing, there are many areas, particularly in the developing world, where Internet is not available. In many cases, the non-availability of the Internet is because of the cost associated with the Internet. The cost associated with Internet provision decreases with the increase in number of users in a particular area. In remote areas, where the number of users is very small, this cost can reach a point where it is not economically feasible for the Internet provider and user to provide or use Internet. In some rare cases, the living conditions of users are such that a stable, always available Internet connectivity cannot be provided. An example of this scenario would be nomadic or semi nomadic people who do not live in one particular place. Because of these reasons, there is a large group of people who are still not part of global internet community.

Delay-tolerant network architecture [1] was proposed to provide connectivity during challenging environments. These challenging environments can include discontinuous connectivity, asymmetric and variable data rates and restriction on cost, energy or other resources. Like Internet, DTN started as solution to some of the military and space related projects but its application in other domains has grown over time. One application of DTNs which has gained popularity is providing Internet services to remote areas. In this paper, a comparative study of different solutions that focus on providing Internet using DTN architecture is presented. Similarities and differences of these solutions have been discussed and propositions have made to improve these solutions.

The rest of the paper is divided as follows. Section II discusses requirements of DTN deployed in rural areas. Section III discusses some of the deployed architectures and their properties. Section IV provides a comparison between architectures discussed in III and discusses some of the limitations of these architectures. Section V gives a few propositions to increase efficiency of these networks and section VI concludes this article.

II. Requirements of a Rural Area DTN

The requirements of a DTN designed for rural area can be different than a DTN designed for military or space use. The primary concern is cost efficient services. Compromises can be made on the efficiency of a network. In this section, a few requirements for rural DTN network are highlighted.

Low Cost

Cost is the primary factor for a network that is deployed for rural areas. The population density is very low and traditional solutions for providing Internet access can be very expensive. Even though with the advent of wireless technologies this cost has been reduced, it can still be very expensive for users, especially in the developing countries. This is the primary reason that solutions like satellite coverage, landline and even 3G connectivity have failed.

DTN makes a compromise on connectivity to provide cheap access. Thus low cost would be the primary factor of success for any DTN deployed for rural areas.

Reliability

Reliability is also a key requirement for a DTN in rural areas. A user should be confident that the network provides the services reliably, even though with large delays. The mechanism of providing reliability will be intrinsically different in a network which suffers periodic disconnection than a network that is always connected.

Efficiency

Even though DTNs provide a compromise on connectivity, it is still very important to provide services as efficiently as possible. This would be vital in developing the trust of users.

Heterogeneous Environment

Network should support all types of user devices capable of using Internet. Similarly, the DTNs should be able to use any available network that is feasible to use. A method should be devised to use different networks like landline, 3G/GSM, satellite and even mechanical backhaul opportunistically.

Mobility

Support for user mobility is also very important. Instead of restricting users to get information from one particular place, information should be delivered to the users independent of their location.

Security

Privacy and security are important issues for every network. DTN networks can particularly prone to security issues as many traditional solutions for security and privacy require a constant connectivity. Thus new mechanisms have to be devised.

Support for legacy services

Many of the Internet service are provided with an assumption that a user is continuously connected. Protocols like TCP require a connected session to transfer data. This condition cannot be guaranteed while using a DTN. In order to utilize these services, the architecture of DTN should take care of the discontinuous nature of network.

III. PROPOSED ARCHITECTURES

This section gives a short review of the currently proposed DTN architectures for rural areas. Some of these architectures have been tested under different projects.

A. *Sami Network Connectivity (SNC)*

Sami Network Connectivity (SNC) was designed to produce internet connectivity to Sami population of Nordic region. The target population of SNC project is semi-nomadic reindeer herders. Services like email, voice/video mail, photograph transfer, file transfer, telemetry and e-government were the primary objectives. It was assumed that in the vast Nordic region, connectivity through wireline, GSM/3G, or satellite was not possible. Instead discontinuous connectivity using WIFI hotspots and mobile relays was considered as the basic mode of communication.

1) *Architecture*

Fig 1 shows the simplified form of architecture considered in SNC project. M1, M2 and M3 are mobile relays that move inside the network. This movement may or may not have a pattern. Some of these relays can communicate with a gateway. Transactions are made in form of bundles between different relays and gateways. Mobility enables different relays to exchange information. Information from relays which do not have direct connectivity with a gateway can be transferred to gateways (G1,G2) with the help of other mobile relays(M2,M3). In this way, an indirect connectivity can be provided to the users of M1.

2) *Routing*

SNC proposes the use of PRoPHET routing protocol which relies on the calculation of "delivery predictability" for decision making. Delivery predictability value is calculated and updated based on the encounters among nodes. A node which is encountered frequently is considered to be more

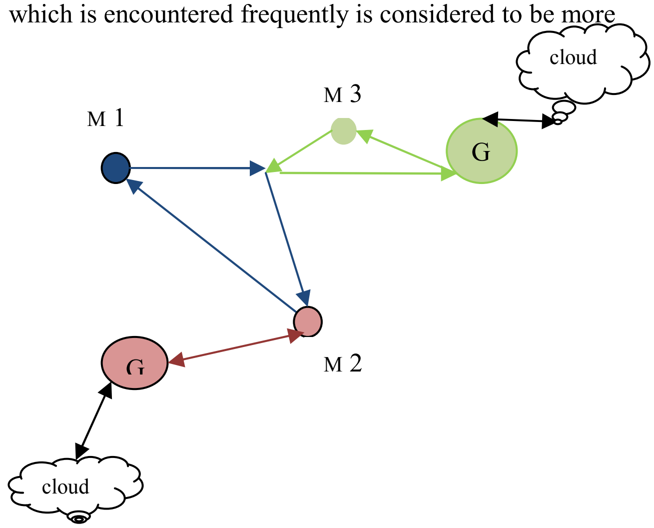

Figure 1 Simplified architecture SNC

reliable in delivering messages. Transactions are joined together to form "bundle" which are later forwarded using PRoPHET protocol.

A. *KIOSKNET*

This network architecture is inspired from DAKNET [2]. DAKNET project focused on providing cheap Internet services to the rural areas of India. It suggested the use of physical means for delivering messages to areas which are not connected via traditional networks. Network architecture suggested in [3] is an extension to this work. Seth et al [3] give a comprehensive model for a network that uses mechanical backhaul for delivery of Internet services.

1) *Architecture*

DAKNET proposed the use of kiosks in a rural village. Seth et al [3] borrow this concept in their architecture. Kiosk work as central hub in village and consist of kiosk controller, a server providing network boot, a network file system, user management mechanism and network connectivity[3]. Users connect to kiosk either via a public terminal that boots over the internet or through their own devices like laptop and PDAs. Kiosk controller acts as a store-and-forward access to Internet.

Kiosk controllers are connected to internet gateways using "ferries". Ferries can be any mechanical backhaul unit e.g. a bus, car, train etc. A ferry is also equipped with a communication system consisting of a battery powered computer with storage and WiFi card. Ferries can communicate with kiosk controllers and internet gateways.

Gateways are located in areas where broadband connectivity to internet is present. Gateways receive message from the "ferries" and forward it to appropriate destination. An important role of gateway is the two way communication on behalf of the users of network. Gateway can communicate with any legacy server and can act as a proxy user to the server. After it receives the required data for a user, it stores the data until it meets an appropriate ferry going in the direction of the user, to which it handovers the data. The selection of ferry is made with the help of routing protocol.

Messages are exchanged in the form of "bundles" as specified in [4]. Multiple proxies can be present in a DTN network so an intelligent selection should be made while sending data from kiosks.

DTN router term refers to a kiosk controller, a ferry or a gateway. Ferry is an example of mobile DTN router whereas kiosk controller and gateway are fixed DTN routers.

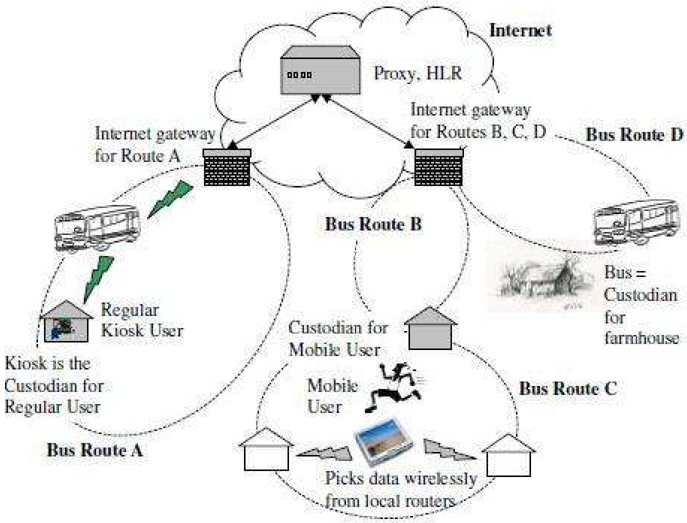

Figure 2 Seth et Al, "Example Topologies" Low cost Communication for Rural Internet Kiosks Using Mechanical Backhaul" Sep 2006

A user must register itself with one of the DTN routers; this router is then called the custodian of the user. Custodian can store data for its users and can also participate in routing of "bundles" for users. Fig. 2 shows some of the explained components and role of custodian in different scenarios.

2) Routing

[3] introduces the concept of GUID which is based on hashing of telephone number (IMSI) or email address to fixed length, unique string. The full GUID of a user is the tuple with two names: [custodian GUID, user GUID]. An entity like HLR is needed to map user GUID to custodian GUID for unbound packets. HLR is updated whenever a user changes its custodian.

Routing is performed at every DTN router by looking at the GUID of a bundle. No particular routing protocol has been specified but three different mechanisms have been suggested. Flooding, reverse path forwarding and link state routing are the suggested schemes. Author argues that routing can be performed in a similar fashion as in internet. The role of routing protocol is to find the next hop link given the custodian/user GUID of the bundle.

B. MOTOPOST

Motopost is another DTN architecture proposed by naidu et al [5]. This architecture proposes the use of mobile phones as data carriers. Instead of providing a wide range of services as KioskNet, it focuses on delivering voice and picture enabled messages.

1) Architecture

Motopost[5] also extends the concept of kiosk[2] in a different way. Instead of making kiosk as a hub for connectivity, kiosk is used to run user applications and provide services (much like a normal pc). Kiosk is equipped with WiFi card and is capable of communicating with BoBs. Box-on-bus are dual mode mobile phones that are used to carry messages. BoBs can be considered as a replacement to ferries of KioskNet. These BoBs communicate with Kiosk and a central gateway known as "Dispatch Centre" (DC). The role of DC is quite similar to that of gateways in KioskNet. It provides internet connectivity to DTN. DC communicates with BoBs using GPRS. Apart from the connectivity, DC also performs the functions of authentication, billing and service portal.

2) Routing in Motopost

Motopost[5] delivers data in the email type messages. The destination field of the message contains the address which is based upon the postal index number (PIN). Every subscriber is allotted a 14 digit ID in the <user-ID,Kiosk-ID,PIN> format. The BoBs are identified with 14 digit address in the form of <BoB-ID, operator ID>.

SMTP relay model is chosen to route messages with some changes. A control protocol is also implemented to exchange routing information and SMTP message transfer schedule before actually transferring the SMTP messages. This control protocol was also used for authentication.

IV. ANALYSIS OF PROPOSED ARCHITECTURES

After setting the requirements in Section II and study of currently used architecture, this section provides a critical analysis of the architectures discussed in Section III.

A. Comparison of available architectures

1) Selection of HotSpots

SNC project focused on semi-nomadic population whereas KioskNet and MotoPost focus on rural areas where people are no nomadic. The main difficulty in providing Internet to Sami population is their nomadic way of life. The population density is very low and coverage of the whole Nordic area with wireless connectivity is not a feasible option. After careful surveying, a few spots can be selected where internet can be provided. Position of these spots greatly affects the performance of network. KioskNet and Motopost focus on areas where population exists in close proximity. They do not move and have well established road links to major cities. Hotspots will naturally be established in these villages.

2) Routing Algorithm

SNC project defines its own routing algorithm PRoPHET[6] which focuses on exploiting the movement pattern and delivery predictability. This is algorithm can have more delays but gives better resource usage. KioskNet does not specify and particular routing protocol instead suggests several protocols that are currently used for routing in internet. MotoPost performs routing on email message delivery format using SMTP protocol.

3) Heterogeneity and mobility

SNC and KioskNet provide more heterogeneous and mobile environment. They do not limit user equipment to a particular device or place and consider all available networks for connectivity. Motopost on the other hand relies on GSM for communication with gateways and the accessibility of services is restricted to Kiosks.

4) Support for services

SNC and KioskNet can support a wider range of services due to their flexible architecture. [seth et al] proposed the use of Opportunistic Connection Management Protocol [7] which can support session persistence and provide use of legacy servers. SNC also insists on providing a wide range of delay tolerant services however the method of providing these services is not available. MotoPost has only been tested for voice and picture messages but claims that other applications can easily be included in the current architecture.

B. Limitations

1) Use of All Available Networks

Although SNC and KioskNet both discuss the use of different network, no method has been specified which could statistically select different networks on the basis of type and volume of traffic. MotoPost completely rules out the possibility of using multiple networks which makes its operation dependent on GSM.

2) Intelligent Routing

KioskNet and MotoPost routing algorithms assume a predefined movement pattern for data ferries. This can be an agreeable solution in some cases but it doesn't exhibit scalability. Any changes to the predefined routes of ferries can hamper the network operation. Instead of relying on predefined paths, an intelligent probabilistic algorithm would handle these situations in a better way. Intelligent routing will also decrease the utilization of common resources which will result in the efficiency of network.

3) Classification of Data

Even though delay tolerant networks are designed to have large delays, it is still important to prioritize different types of data. Ferries can carry a limited amount of data in one time and it is possible that because of huge amount of data, not all data at a Kiosk or node be transferred at once. It is particularly important for networks like KioskNet and MotoPost to deal with such situations. A scheduling algorithm depending on prioritization of different types of data is necessary for these architectures.

V. PROPOSED CHANGES

This section proposes a few changes to increase the efficiency of the discussed DTNs. These solutions can be extended to all three architectures.

A. Caching

As DTN is designed to provide only a subset of services of internet, it is very likely that users in one area request for the same information. For example an important application of DTN in rural areas is to provide e-government facilities to local people. There is a high probability that many user may request for similar forms. Similarly, another use of DTN in rural areas is to provide agricultural information which will be common for local farmers. Instead of requesting for similar information, it will be wise to cache this content locally.

In case of KioskNet, users normally connect to through the local Kiosk. By introducing the function of caching in Kiosks and giving it a new role of proxy, efficiency of the network can be increased significantly. However, some parameters needs to be defined that could predict the age and life time of cached material.

B. Statistical Use of Different Networks

DTN solutions discussed above mostly focused on the use of mechanical backhaul. This is because of the assumption that either no other networks are present at all or if present, they are too expensive. Both SNC and KioskNet discuss the possibility of using multiple networks but do not discuss the criteria of selection of different networks. KioskNet suggests the use of OCMP[7] which can use all available networks but leaves the decision of selecting network to the application. We believe that sometimes, a network which is usually not the preferred choice (e.g. satellite communication), can be feasible to use. E.g. the cost of satellite link may depend on the amount of data to be sent. If the data is large, cost/bit will be low. Thus for scenarios where large amount of data has to be sent, statistical use of satellite link can be justified.

Similarly, if a small amount of data is waiting for a ferry for a long time, it would be better to use a dialup connection (that charges on time basis) and send data than to wait for a ferry whose probability to come is very low.

Thus it would be useful to provide connectivity using different networks depending upon the cost/bit and current conditions. A mechanism is required at the connectivity hub (e.g. Kiosk) to make such decisions.

C. Local Information Sharing

DTN should provide support for local information sharing inside a disconnected zone. This service can be extended as a form of peer to peer communication or by using communication hub (e.g. Kiosk) as a master and user equipment as slaves. People in same area share interests and it is highly probable that the information they seek is available with another peer inside the disconnected zone. This will help in creating a better data sharing environment and will increase the performance of network. Peer-to-peer applications can be developed to attract subscribers.

VI. CONCLUSION

DTNs can play an important role in the development of rural areas. Recent growth in wireless communication industry can bridge the gap between DTNs and traditional internet. DTN can provide only a subset of services provided by traditional internet but these services can be very beneficial.

Currently deployed architectures of DTN are developed as a solution to local community and vary on some levels. However, there are many common problems faced by these architectures. Efficient routing, statistical use of all available networks and classification of data are some problems that were discussed in this article. Solutions to these problems should be formulated by careful designing to ensure generic approach. This will help in standardizing an architecture and will bring close the existing architectures.

Some additional features to these architectures are also proposed. These propositions apply to all architectures discussed in this article and will improve the efficiency of deployed networks.

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