On Delay-Tolerant Networking and Its Application

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Abstract. Nowadays, the research and application about delay-tolerant network (DTN) have become more and more popular. DTN is a new kind of network derived from deep space communication. Differed with traditional network, DTN network has the following several characteristics: long delay, limited resources, interval connectivity, asymmetric data rate, low signal to noise ratio, and high error rate. In this paper, we present the development and basic characteristics of DTN, and discuss the network architecture in details. In addition, the issues of reliability transmission, congestion control, security and applications are also be covered in this paper

Keywords: Delay-tolerant network, DTN Network protocol, DTN network model, DTN application

1. Introduction

Through the network transmission has been very easy thing at current , but it is still very difficult to transmit data in some networks that are often in delay and interruption. Meanwhile, network interruption and delay are very common due to various reasons such as the change in network topology or harsh environment, etc. In order to address this concern, many researches have proposed many solutions over the last ten years. However, such approaches are all try to address the issue based on the traditional network protocols so that these schemes are not feasible in some specific cases, which resulted in a concept of DTN. Thus Fall in 2003 firstly proposed the concept of Delay Tolerant Network (DTN). Later, Internet Research Task Force (IRTF) established DTN Research Group (DTNRG)based on the Interplanetary Network Research Group (IPNRG) to research the DTN, and in 2007proposed the DTN network architecture [2] and Bundle protocol (BP) [3]. Later in 2008, it proposed a series of convergence layer protocols including Licklider Transmission Protocol (LTP [4]) and Saratoga [5] to improve the BP protocols. Since then, many researchers have been focus on the DTN related fields and do some concrete deployments and experiments. For example, England designed a United Kingdom Disaster Monitoring Congestion system[6], Sami Network Connectivity experiment in northern Sweden [7], the DieselNet vehicle network experiment in United States [8], Zebra monitoring network system in Africa [9], Whale monitoring network system [10], and the experiment using sensor nodes or mobile phone are the typical example. These experiments show that although there are still some problems in DTN, The DTN can provide effective network services even in the region that is not covered in existing network or special conditions.

In this paper, we focus on the discussion of the DTN's network characteristics, system and layer architecture, network protocols, reliable transmission, congestion control, and applications. The rest of the paper is organized as follows: the next Section we briefly review the basic features of delay-tolerant network. The network architecture and some especial issues will be discussed in Section 3. In Section 4, we give some application of DTN. Finally, we draw a conclusion and points out the future research trends in

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section 5.

2. The basic Features of Delay-Tolerant Network

Compared to traditional Internet, mobile ad hoc networks, WLAN, DTN network have the following basic features [1]:

2.1. Intermittent Connection

As the node's mobility and energy are limited, DTN frequently disconnects , thus resulting in continue change in DTN topology. That is to say, the network keeps the status of intermittent connection and partial connection so that there is no guarantee to achieve end-to-end route.

2.2. High delay, low efficency, and high queue delay

End-to-end delay indicates that the sum of the total delay of each hop on the route. The delay is consisted of waiting time, queuing time, and transmission time [1]. Each hop delay might be very high due to the fact that DTN intermittent connection keeps unreachable in a very long time and thus further leading to a lower data rate and showing the asymmetric features in up-down link data rate. In addition, queuing delay plays a main role in end-to-end delay and frequent fragmentations in DTN make queuing delay increasing.

2.3. Limited resource

Node's computing and processing ability, communication ability and storage space is weaker than the function of an ordinary computer due to the constraints of price, volume and power. In addition, the limited storage space resulted in higher packet loss rate.

2.4. Limited Life time of node

In some special circumstances of the restricted network, the node is common to use the battery power on the state of hostile environment or in harsh conditions, which will cut the life time of node. When the power is off, then the node can not guarantee normal work. That is to say, it is very possible the power is off when the message is being transmitted.

2.5. Dynamic topology

Note that the DTN topology is dynamic changing for some reasons such as environmental changes, energy depletion or other failures, which results in dropping out of network. Or, the requirements of entering DTN also make topology change.

2.6. Poor Security

In general, DTN is vulnerable to--besides threats of wireless communication network--eavesdropping, message modification, routing spoofing, Denial of Service (DoS), and other security threats, etc, due to the lack of specialized services and maintenance in real-world.

2.7. Heterogeneous interconnection

DTN is a overlay network for transmission of asynchronous message. Introducing the bundle layer, the DTN can run on different heterogeneous network protocol stacks and DTN gateway ensures the reliable transmission of interconnection message.

3. The Network Architecture

3.1. System Structure

A typical DTN system structure is illustrated in Figure 1[13], which includes DTN gateways and four heterogeneous regions with different communication protocols, where region A is an Internet region, region B is [12] rural networks in remote areas including a mobile gateway that will ferry between gateway 3 and gateway 5, region C is the sensor network, and region D is satellite networks including a LEO satellite link that allows cycle connection. Note that the nodes in the same region can communicate with each other by local region communication, and nodes in different region want to communicate with each other with the help of DTN gateway at the point of regional borders [9].

3.2. Layer Architecture

DTN is the end-to-end transmission overlay network that is asynchronous message-oriented. Its architecture is different from the Internet architecture [2]. The DTN introduces the bundle layers between the transport layer and application layer in heterogeneous network. The bundle layer provides the function of persistent storage due to store and forward mechanism. And to achieve the interoperability among heterogeneous networks, it uses naming mechanism based on URL and message encapsulation mechanism.
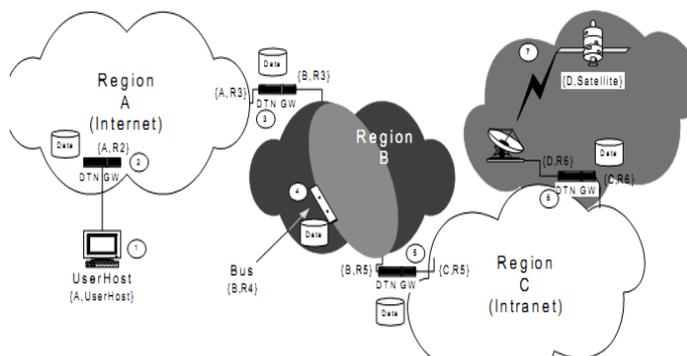

Figure 1. The Architecure of Delay Tolerant Netowork

Naming mechanism employs the name tuple to identify DTN node and the format of naming tuple likes the form of (region name, entity name), where region name is unique in the world and divided by class.,similar to Domain Name System(DNS) in route, and it is not required to process address resolution and entity name identifies a specific name that can be resolved within that region..So, it is not unique, arbitrary type and length outside region. Bundle layer uses the custody transfer mechanism to realize the message retransmission and confirm among nodes, thus increasing the reliability of message transmission shown in Figure 1. The message in bundle layer is called bundle which is consisted of bundle header, control information and application data unit (ADU), which provides some services such as custody transfer, receipt of accepting, announcement of custody transfer, announcement of forwarding bundle, priority, and authentication. Now we give the layer architecture of DTN according to the [1, 2, 13].

1. Application Layer

The layer is by determining the nature of the communication between processes to meet the needs of users. For example, NTP protocol providing time synchronization and FTP protocol supporting bundle transmission, CFDP Transfer Protocol of CCSDS File in space communications, etc.

2. Bundle Layer

 Bundle layer includes bundle API, bundle fragmentation and reassembling, convergence layer adapter (CLA), bundle encryption, authentication and routing, etc. CLA is responsible for providing the bundle mapped to the service of lower layer and providing the mapping in the TCP protocol, UDP protocol, LTP protocol or directly in link layer. This bundle layer employs overlaying layer protocol based on storage and forward, namely bundle protocol. The main function of the protocol is message retransmission based on custody transfer, and uses the opportunity connection to address the problem of intermittent connection in network to provide the late binding mechanism [14].

3. Transmission Layer

Transmission layer is responsible for transmission control and congestion control such as TCP protocol, UDP protocol and LTP protocol. LTP provides the reliabilty of retransmission which is applied in the CCSDS space link protocols.

4. Network Layer

Network layer is responsible for discovery, establishment and maintenance in the route.

5. Link Layer

 Link layer is responsible for framing data, checking the frame,and media access and error control including protocols of Ethernet, MPLS, PPP and CCSDS space link protocol, etc.

6. Physical Layer

 This layer is responsible for modulating data, sending and receiving data, selecting channel, and transiting bit stream transparently using physical media.

3.3. Typical Protocol

The bundle protocol proposed by DTNRG is an overlaying network protocols [13-14] running on a specific area of different types of underlying protocols such as existing Internet protocol, deep space communication, complex sensor network and some challenged networs. Figure 2 shows the bundle protocol model. There are three different transmission and network protocols representing in T1P N1, T2P N2 and T3P N3. There protocols have the following features including:

1. retransmission based on custody transfer,
2. the process of intermittent connection,
3, being able to use connection of reservation, forecast and opportunity,
4, the network address is formed by identifier binding to the node in overlaying layer.
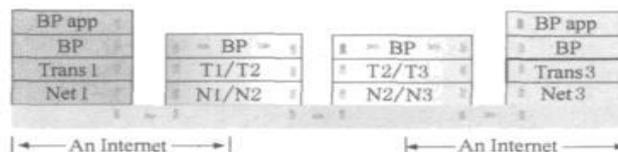

Figure 2. The bundle protocl sits at the applciaiton layer of the Internet model.

RFC5050 discussd the concept of bundle protocol including basic terms, bundle format, process of bundle and management record in details. The protocol constructs storage and forward overlaying network, and has a "convergence layer adapter ". The protocol achieves the function of sending and receiving bundles using the underlying network protocol. In [17], the draft gives the DTN-TCP protocol of convergence layer based on TCP protocol.

LTP can handle delays and interruptions of point to point communication; especially in the long link delay problem. One of the typical application examples is the solution of deep space communication problem between space shuttle and station in one hop. That's to say, if a spacecraft would soon hide behind a planet, it can't again send LTP data, and before planet appearing out of the shadows it don't get reply for perivous data, when aircraft can "freeze" all the timer to handle this shadow time, once appearing again LTP can restart them. This method of "freezing" or marking timer is the key thought of LTP protocol. LTP is a point-to-point protocol, so need not consider routing or congestion control problem. Also, LTP protocol can support bundle protocol, so it can configure bundle protocol. In addition, LTP protocol applies to the situation where the ground network has a lot of disruptions. Till to now, there are three drafts and later versions of LTP description [18-20].

Saratoga is a lightweight distributed protocol using UDP protocol. The purpose of the protocol is to provide the reliability of transferring files or data streams under intermittent connection. Saratoga protocol is used for solving the problems caused by asymmetry communication link or path, If in need, it can support a complete one-way data transmission. In special link, by raising link utility Saratogato makes full use of limited connection time, while standard congestion control mechanism can also be used in sharing link through simple ARQ mechanis to achieve lost package control. The draft [21] describes how to use Saratoga to achieve the reliability of DTN bundle exchange between agents.

Beside the bundle protocol and LTP protocol, draft [22] also defines the principle that the application of bundle protocol should agree with. Draft[23] extended the bundle protocol and draft[24] provides a mechanism of when bundle proxy in the overlaying network is to exchange information with current or future link. As you can see, protocol systems based on DTN environment have become gradually better due to bundle protocol as a core protocol. However, RFC or Draft mentioned above are not covering the network protocol blew the application layer, especially routing protocol, still staying in a hypothesis that its available state.

3.4. Custody Transfer and Reliability

In DTN, continuous end-to-end connection cannot be assured, any point-to-point link may be interrupt at any time, be unable to timely monitor data rate, and buffer occupancy rate cannot dynamically change. On the contrary of TCP, DTN protocol does not include end-to-end confirm mechanism that can be as a vehicle for promptly correct action at source. In view of the above characteristics, hop - hop custody transfer mechanism has been proffered to improve the reliability of the network includes custody acceptance or custody refusal [13]. Custody transfer that assumes responsibility of reliable transmission is a special kind of mobile message toward the destination in hop - by - hop way [15]. Custody transfer can guarantee

reliability to some degree as the custodian node cannot discard message unless its life time expires or be transferred to another node after commitment [16]. On the other hand, one advantage of custody transfer is that custody transfer ACK can make node release buffer relatively quickly as it is likely that custody transfer occurs between relatively close nodes, which can keep its round - trip - time less than the end-to-end round-trip-time. Anyhow, the function of custody transfer is by using reliability of hop-by-hop (custodian-to-custodian) to improve the end-to-end reliability and soon release the sender's retransmission space.

3.5. Congestion and Flow Control

Compared with other networks, DTN congestion control is relatively difficult due to two characteristics. First, in some time in the future it may not be able to establish a connection so accumulative data cannot be sent. Second, unless in extreme circumstances or expired the custody message that has been received can not be discarded. At present, DTN uses FCFS based on priority to allocate custody transfer. If DTN node accepts too much message out of "the contract", then the network will appear congestion. If so, the long-term storage of node could be completely consumed. Accordingly, to avoid transferring non-custody messages, the congestion control mechanism can be divided into two types of procative and reactive. The procative mechanism typically avoids congestion by access control approach at the beginning. This method is practical as in many cases a single area may be under control management of a single entity. In addition, if the procative mechanism is not available, the reactive one will run at the cost of poor performance.

3.6. Security

Current mature encryption and signature algorithm in Internet is not applied in DTN for its extreme environment, plus its unique bundle protocol layer, which makes DTN urgently need a new network security mechanism. Some examples as core of security mechanism are bundle protocol security, node authentication, data encryption, message integrity check, etc. The ability of communication, storage, computing power of nodes in DTN is weaker, so the security of node is of paramount importance. And node should identify malicious illegal node to prevent itself sending large junk data as a legitimate node to congest network, therefore, there is a need that for all nodes and users carrying out a compulsory authentication. Its security protocol is expected to encrypt and signature bundle to prevent malicious attack and monitor behavior, and at receiving node to authenticate each fragment to keep confidentiality, integrity, and usability of bundle load data. Also, it must have anonymous protocol that, when sending nodes and receiving nodes can "know" each other, hiding the identity to the attacker and eavesdropper. DTN network has wide applications, but its security problems cannot be ignored. Furthermore, its various security mechanisms also need more in-depth study to further perfect DTN security features.

4. Application

4.1. Deep Space Exploration

In the next few decades, NASA and other agencies will plan a series of projects of lunar exploration, Mars exploration and others. In September, 2003, Cisco router (CL EO) was launched by satellite to monitor disaster in UK. Till to December 2008, CL EO has done a lot of routing tests in space environment including using Saratoga protocol of bundle layer instead of pervious protocol making full use of the link source to overcome serious asymmetry link conditions. The experiment shows it is feasible to use Bundle Protocol [25] in space.

4.2. Studies of wild zebra

The Zebranet project [26] has installed a global positioning system (GPS) in a zebra collar to study the habits of zebra activities, which is one of the early DTN projects and was started in 2004. Collars start every few minutesr to record GPS location information, and every 2 h open radio function, when two collars' distance is in communication range they would exchange information (adopted Epidimic routing algorithms). After a period of time, every horse collar stores the position information of others activities. In this experiment, the researcher can know the exact location of zebra only with little information. The further experiment of this project is to resolve the issues of equipment energy, adaptability and data compression.

4.3. Rural Communication

There are many rural communication projects in remote villages to provide the access to Internet. Some of which is try to reduce the cost of communications using the way of asynchronous information transmission. For example, Wizzy digital courier service provides Internet access for some village schools in South Africa.This project adopted a simple one-hop delay network, letting couriers drive a motorcycle with USB storage device to come and go between rural schools and cities with permanent Internet connection (such a round-trip may take several hours of time), so as to realize the connection between the school and the Internet.

4.4. Lake Quality Monitoring

European Union advises state and local government to launch protect water quality activities [27], in this project, the researchers didn't choose end-to-end communication mode, but using special node (data mule) in the laket to cruise, realizing DTN storage and forwarding mechanism. When the ship (data mule) back to dock, mule can exchange information with the gathering nodes accessing Internet. In this project, using data mules--besides low overhead--still can be independent with infrastructures and set flexibly in various carries. Other one such as Ad hoc being used for collecting battlefield information or collecting data in depopulated area is actually one application of DTN.That's to say, DTN has come into people's lives. Notice that with further development of DTN research, its range of applications will be larger, and more fields will be benefited.

5. Conclusion

In this paper, we introduce features of delay tolerant network. First, we introduce the basic ideas about the origin and basic characteristics of DTN. Then, we discuss the DTN system structure , several typical network protocols and some key issues such as reliability transmission, congestion control, and security in DTN in details. Finally, we present some application domains of DTN. Note that the DTN architecture is a fundamental change not just supplement to Internet and it employs a series of different design concepts. For example, the message instead of the packet, secure and reliable hop-by-hop communication instead of the end-to-end communications, the name-based routing instead of the routing based on address, and local connection instead of global connection. DTN can be easily compatible with existing TCP/IP protocols. There are many potential DTN applications such as Mobile Ad hoc Network, IPN wireless sensor networks, and other challenged network environments. The main purpose of DTN is to provide network solutions to meet the reliability of free transmission of asynchronous messages at limited end-to-end connection and resources. The research and development of DTN will be applied to the military war, disaster recovery, emergency rescue and other environment, which will benefit the development and strongly further the Intelligent, Ubiquitous, Integrative trend of Next Generation Network (NGN).

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