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Buffer Management in Delay Tolerant Networks

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Abstract—Delay tolerant networks (DTN) are networks which are applied in extremely tough networking environments characterized by high latency, disconnections, error probabilities and limited resources. Routing and buffer management are two important issues in DTN. Routing strategy determines which message will be forwarded when node comes in contact with another node. Buffer management strategy determines which message will be dropped when node buffer overflows. These strategies are used together to increase delivery rate, reduce delay, improve message dissemination and improve network performance in DTNs. These strategies can be divided into two categories: policies without utilizing network-wide information and policies utilizing network-wide information.
Keywords-Delay tolerant networks; routing; buffer management; buffer replacement policy; packet drop; buffer scheduling policy.

I. INTRODUCTION

Delay tolerant networks are a category of networks where there are long duration and frequent partitions. Some examples of these networks are interplanetary networks, sensor networks, military ad-hoc networks, vehicular networks, etc. Traditional TCP/IP protocol uses a fully connected end-to-end path between a source and destination. But in DTN an end-to-end communication path may not be present. Messages are delivered to their destination hop by hop using a store-carry-forward paradigm. In a store-carry-forward routing, if the next node is not immediately available for the current node to forward the message, the node stores the message in its buffer until it gets an opportunity to forward it further.

There is a problem of how to schedule and drop messages in a buffer, due to the unpredictable mobility of nodes in DTN . Many routing protocols of DTN use flooding based schemes to improve message delivery where a node receives message, stores it in its buffer, carries it when it moves and forwards it when it encounters other nodes. The excessive multi-copy forwarding causes congestion and exhausts the buffer space of nodes which affects the performance of the network adversely. Thus the performance of routing protocols in DTN is significantly affected by how buffers of the nodes are managed. So buffer management is important to achieve good network performance in terms of increasing data rate and reducing latency.

There are two types of buffer management policies: policies without utilizing network-wide information and policies utilizing network-wide information. Based on these policies buffer management schemes are created. Two schemes are given in this paper: Scheme based on message transmission status and comprehensive-integrated buffer management scheme. Comparison of these schemes with FIFO is given.

II. LITERATURE SURVEY

Many buffer management schemes have been proposed in DTNs as the choice of buffer management has a major impact on system performance. Some buffer management strategies can be performed independent of underlying routing algorithm. Three buffer management strategies like drop-head, drop-tail and source-prioritized drop-head are examined by using Epidemic-IMMUNE routing protocol. It showed that appropriate buffer management schemes had negligible effect on delivery performance. Krifa et al [3] proposed a distributed algorithm based on estimated global information to optimize the specific metrics. However, this method calculates metrics depends on specific parameter of mobility models.

Some buffer management strategies depend on underlying routing algorithm. Lindgren et al. used delivery predictability metric defined in PROPHET [3] routing protocol to decide which message forward first. They evaluated different combination of queuing policies and scheduling strategies using PROPHET[3] for intermittently connected networks. Khelil[3] exploited contact-based mobility metrics to design buffering scheme for a mobility-aided broadcasting protocol called Hypergossiping Erramilli et al. designed scheduling and replacement algorithms based on the message priority that defined in delegation forwarding. It assigned message priority according to their distance to destination. Krifa et al.[3] suggested a joint scheduling and drop policy called Global Knowledge Based Scheduling and Drop[3], that can optimize different performance metrics such as the average delivery rate and the average delivery delay. This policy was difficult to implement in practice. Therefore, they presented a second policy called History Based Scheduling and Drop.

Adaptive optimal buffer management scheme for realistic DTNs where the bandwidth was limited and messages varied in size. The mobility model was adjusted according to the nodes historical meeting information, and the message dropping policies were designed to optimize certain network performance goals, such as maximizing the average delivery rate or minimizing the average delivery delay.

III. BUFFER MANAGEMENT IN DTN

When the buffer of nodes becomes full and a new message is to be accommodated, a buffer management policy is necessary to decide which message to be dropped. The existing buffer scheduling and management policies mainly can be broadly divided into two categories-policies: policies that do not need network-wide information, which only depend on local information about messages, such as arriving time, TTL, and size, to decide how to management the messages in the buffer; and policies that is based on the partial or complete network-wide information, which make buffer management strategy not only relying on local information but also considering the partial or complete network-wide information including number of nodes in the network, number of copies of message, meeting rate between two nodes, etc.

3.1. Policies without network-wide information

The authors evaluate the performance of some buffer management schemes, these schemes only utilize local information instead of network-wide information to decide which message to be dropped first for the condition of finite buffer of nodes. These policies are as follows.

1. DL-Drop Last: the newly received message is first removed simply.
2. DF-Drop Front: handles the message queue in a FIFO order based on their receiving time. The message that was first got into the queue is the first message to drop when the buffer is overflow.
3. DO-Drop Oldest: deletes the message with the shortest remaining life time (closest to TTL expiration) is deleted firstly.
4. DY-Drop Youngest: the message with the longest remaining life time is deleted firstly.
5. DLA-Drop Largest: in which small size messages can get more chance to be forwarded and big size messages are to be selected to drop when the buffer is full.

3.2. Polices utilizing network-wide information

Based on the network-wide information several buffer management methods have been proposed to enhance the network performance. Some of them are utility-based schemes, which use the complete information of messages related to the whole network to derive a per-utility for a certain routing metric (e.g., end-to-end delay, delivery rate) and manage messages based on the utility. By deriving the per-message utility these schemes can maximize the average delivery rate or minimize the average the delivery delay. However, for opportunistic networks, it is not easily to obtain the global network information in practice. Then, other proposed methods merely take partial network-wide information into account instead of relying on deriving utility function to decide the scheduling and drop policies in order to improve the performance of networks.

3.2.1. Utility-based optimal policies

RAPID(Resource Allocation Protocol for Intentional DTN) [5] is the first utility-based buffer management policy. In RAPID[5], given limited bandwidth, how messages should be replicated in the system so as to optimize a specific routing metric is a key question. RAPID[5] derives a per-message utility function from the routing metric. At a transfer opportunity, it replicates a message that locally can provide the highest increase in utility. Considering a routing metric such as minimizing average delay of messages, the corresponding utility U of a message i is the negative of the expected delay to deliver i, i.e., the time has already been spent in the system before i's copy reaches its destination. Let δUi denote the increase in utility by replicating i. Then, A RAPID node firstly replicates the message with the highest value of δUi among messages in its buffer. In other words, the message with the highest marginal utility is firstly replicated. In general, Ui is defined as the expected contribution of message i to the given routing metric. For example, the metric minimizing average delay is measured by summing the delay of all messages. Accordingly, the utility of a message is its expected delay. Thus, RAPID is a heuristic approach based on locally optimizing marginal utility, i.e., the expected delay in utility per message used.

3.2.2. Partial network information-based policies

Since the topology of the opportunistic networks usually varies frequently, complete network-wide information cannot be obtained in time. So many buffer management decisions are designed to improve certain metrics of message delivery based on partial network information (e.g., the number of copies of message in the network, the meeting frequency between pair nodes) instead of all network-wide information correlated with messages. For instance, in MOFO-Evict most forwarded first, the message with the largest number of copies in network has been dropped.

IV. BUFFER MANAGEMENT SCHEMES

Two buffer management schemes are studied. These are as follows:

4.1 Scheme based on Message transmission status

4.2 CIM strategy

4.1. Scheme based on message transmission status

Delay tolerant networks (DTNs) characterize a class of emerging networks that suffer from frequent and long-duration partitions. As the storage-carry-forward paradigm is adopted to transfer messages in DTNs, buffer management schemes greatly influence the performance of routing protocols when nodes have limited buffer space. From a network-wide viewpoint, the excessive increase of a single message's copies will exhaust nodes' buffer space, thus reduces the probability of other messages to be buffered and forwarded and leads substantial decrease in their delivery ratio. In this scheme, inspired by the law of diminishing marginal utility in economics, a buffer management scheme based on estimated status of messages is proposed, e.g., the total number of copies in the network and the dissemination speed of a message. When performing buffer replacement and scheduling, nodes use encounter histories to estimate status of messages and act accordingly: when buffer overflow occurs, messages that have larger estimated number of copies and faster dissemination speed are replaced prior to and forwarded posterior to other messages. Results show that the buffer management scheme can improve delivery ratio and has relative lower overhead ratio compared with other buffer management schemes.

4.2. A comprehensive-integrated buffer management strategy for opportunistic networks

Opportunistic networks aim to provide reliable communications in an intermittently connected environment. The research in cache management of opportunistic networks has been done a lot in those aspects, such as queue strategy, cache replace, redundancy delete, etc. But most of the existing studies only focus on a subdivision of the buffer management. To deal with such case, this article proposes a comprehensive integration buffer management strategy, called comprehensive-integrated buffer management (CIM), which takes all information relevant to message delivery and network resources into consideration. The simulation experiments show that the CIM strategy improved the performance in terms of delivery ratio, overhead ratio, and average delivery delay.

Opportunistic network has captured much attention from researchers in recent years as a natural evolution from mobile ad-hoc network. It utilizes the communication opportunities arising from node movement to forward messages in a hop-by-hop way, and implements communications between nodes based on the manner of storing–carrying–forwarding transmission. Opportunistic networks are characterized by sparse connectivity, forwarding through mobility and fault tolerance. To deal with the unpredictability in connections and network partitions, many routing protocols adopt flooding-based schemes to improve the message delivery, where a node receives packets, stores them in their buffers, carries them while moving, and forwards them to other nodes when they encounter each other. The excessive multi-copies spraying in the network causes serious congestion and exhaust nodes' buffer space, thus influences the performance of transmission dramatically. Therefore, the buffer management plays a very important role in the transmission, and the limited buffer in each hop should be used reasonably. How to design an efficient and effective buffer management strategy in opportunistic networks becomes a crucial issue.

The main objectives of buffer management are (a) to delete the redundant information in the system, (b) to formulate reasonable queue strategy, (c) to control congestion, and (d) to build up the cache replacement policy. There has been prior work done in designing buffer management strategies.

V. COMPARISON OF THE BUFFER MANAGEMENT SCHEMES

Table 5.1. Comparison of buffer management schemes

Sr. No.	Parameter	FIFO	Message Transmission Status Scheme	CIM Scheme
1.	Average delay	Very high	Less than FIFO but greater than CIM	Very low
2.	Average delivery rate	Very low	Higher than FIFO but lower than CIM	Very high
3.	Overhead ratio	High	Higher than CIM	Low
4.	Overall performance	Poor	Good	Best
5.	Information needed	Does not use network wide information	Use network wide information	Use network wide information
6.	Policy	Local information of a node	Partial policy	Utility based policy
7.	Dropping policy	Drops message received first	Uses simple dropping algorithm	Uses complex utility calculation
8.	Congestion control	No congestion control	No congestion control	Congestion control function is used
9.	Application	Combined with other policy	Sensor networks	Vehicular networks

VI. CONCLUSION

Opportunistic networks aim to provide reliable communications in an intermittently connected environment. DTN is expected to become more useful in next generation internet structure. The DTN architecture aims to address the desire to provide interoperable communications between and among a wide range of networks which may have exceptionally poor and disparate performance characteristics.

A wide classification of scheduling and dropping policies is done. It is important to decide which policy should be applied to a given network scenario. Buffer management policies described provide fairness among messages hence improve overall performance and achieve higher delivery ratio compared with other buffer management schemes, and have relatively lower overhead ratio.

Buffer management schemes in a DTN should be designed considering the limited storage of nodes and the short contact duration between nodes. In this paper we have tried to present a variety of buffer management schemes that are generic for any routing protocol and specific for some routing protocols. It would be interesting to combine various message scheduling and message dropping policies and study their effects on various routing protocols designed for DTN.

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