PSD: One-to-Many Routing Protocol for Publish/Subscribe Applications in DTN

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Abstract. More and more applications appear in delay tolerant networks (DTN) with the popularity of mobile devices such as smart phones and PDAs. The one-to-many routing nature of Publish/Subscribe applications brings new challenges to DTN routing design. This paper proposes a one-to-many routing protocol (PSD) for Publish/Subscribe applications in DTN, which combines two one-to-one routing protocols of Spray&Wait and epidemic routing. Simulations confirm that PSD can achieve high delivery rate, low latency and low cost.

Keywords: DTN, publish, subscribe, routing, one-to-many.

1 Introduction

With Bluetooth and WiFi technology widely exploited today, mobile devices such as smart phones and PDAs can easily form networks to exchange information or share data [1]. Such kind of networks are feature of that there may not exist a complete message routing path between source and destination, for the links between nodes aren't always connected, which is called delay tolerate network (DTN) [2].

DTN brings more and more new applications to our daily lives. For example, shopping centers, fast food restaurants and cinemas, etc. want to advertise their product information to the public. People who are interested in such news may hope to receive them periodically by their mobile devices. However, such kind of publish/subscribe (Pub/Sub) applications bring new challenges in DTN environment.

Pub/Sub problems in DTN need to consider performance metrics of delivery rate, delay, and cost. Firstly, users always need to receive the subscribed news in certain time interval, so the message delivery rate should be high and the delivery latency should be limited by the timeliness of the news. And communication power consumption is one major concern for handheld devices, which requires the news dissemination to limit the number of rely times.

Most previous researches in Pub/Sub system are implemented under the assumption that there is a complete path between source and destination. Relay node forwards the message to next hop without storing the message. In DTN, the node may carry the

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message when no links around itself can be used to transmit it. As a result, traditional Pub/Sub routing algorithm cannot completely meet the requirement in DTN environment.

DTN routing strategy based on replication usually injects a number of copies into the network, where any copy reaching the destination represents a successful delivery. The core of such a mechanism is to determine an optimum number of injected copies. The easiest way is direct transmission [3], where the source node keeps the message until it encounters the destination node, which will not add additional overhead, but the delivery latency is high and the delivery rate is low. Conversely, epidemic routing [8] increases the number of copies to ensure delivery rate and latency, in which the message will be copied to all its neighbors when the message holding node encounters other nodes without that message. Redundant messages will be largely increased in epidemic routing. It is important to limit the times of transitions or the number of copies in performance optimization. Spray&Wait routing [5] injects a fixed predefined number of copies into the network. In each encounter, the node holding messages will assign half of the tasks to the meeting node. In such routing, fundamental metrics like message delivery ratio, goodput, and end-to-end delay are greater than routings introduced above, which causes wide attention of scholars. However, all the DTN routing protocol only focus on one to one message delivery problem. Previous DTN routing protocols [6-7] cannot fully comply with Pub/Sub application demand, which is one-to-many routing as its nature. We propose a routing strategy called PSD for Pub/Sub problem in DTN, which aims to achieve the tradeoff between deliver rate, latency and cost. The core of PSD is to combine Spray&Wait routing and epidemic routing together to fulfill the target of one to many message dissemination in DTN.

In PSD, publication sources will inject certain number of copies of current news into the network according to the number of subscribers. The routing process of such messages is mostly conducted under the protocol of Spray&Wait. However, subscribers and helpers (non-subscribers satisfying some condition) will operate in limited epidemic transmission style for its last copy of current news. By integration of Spay&Wait and epidemic transmission, PSD achieves flexibility in solving one to many routing problem of Pub/Sub in DTN.

The contributions of this paper are: (1) we propose a new routing protocol of PSD, which solves one to many routing problem for Pub/Sub applications in DTN; (2) Extensive simulations confirms performance of PSD on delivery, rate latency and cost.

The rest of the paper is organized as follows. Section 2 presents the design of PSD. Section 3 discusses the simulation results in details. Section 4 concludes this paper.

2 Design of PSD

In this section, we first review the design of Spray&Wait routing protocol in Section 2.1, which is the basis of PSD. Section 2.2 presents the core design of PSD, which focuses on illustration of difference between PSD and Spray&Wait. Section 2.3 gives an example of PSD routing scenario.

2.1 Introduction on Spray&Wait

In Spray&Wait routing [5], the number of message copies is determined by the source node. This protocol contains two components in message routing process: Spray stage and Wait stage. At Spray stage, when one node carrying news encounters another node that hasn't cached this news, it will relay this news to that node and gives it half of the copies. Then half number of copies will be further relayed by that node. When there is only one copy left, the node will go into Wait stage. The node in Wait stage will hold the news until the target node appears, and deliver the message to the target node, which finishes the delivery process of this news.

Spray&Wait routing can achieve the balance of delivery rate and cost in one-to-one routing. PSD scheme is to improve Spray&Wait routing to fulfill one-to-many routing nature of Pub/Sub applications, containing three major differences which will be discussed in details in next section.

2.2 Core Design of PSD

In Pub/Sub applications, there will be many nodes who subscribe to the same source. The number of the subscribers is dynamically changed over time. The target of Pub/Sub applications is to make sure that all subscribers can receive the news published from the source before such kind of news messages loses its effectiveness. Therefore, for Pub/Sub applications the success delivery contains a time limit in its nature, which shows delivery latency should also be taken into consideration.

As mentioned above, Spray&Wait routing protocol aims to deliver one copy of message from one source to one target. The source injects predefined number of copies into the network to ensure certain deliver rate of that message. The first difference between PSD and Spray&Wait routing is that the number of copies injected by the source is determined according to the number of subscribers in PSD, not like according to the target delivery rate in Spray&Wait routing. We will show that there is no need for the copy number of published message to be higher than the number of subscribers in the simulation section, which helps in limiting the delivery cost and still keeps certain delivery rate.

It may be questioned how every subscriber can get one copy of the news message, if the copy number of that message is lower than the subscriber injected by the source. The answer lies in the second difference between PSD and Spray&Wait. PSD changes the method of direct transmission of Spray&Wait routing in Wait phase, which exploits limited epidemic routing in that phase. The word "limited" is to illustrate that such kind of epidemic transmission does not happen between any nodes in Wait phase. Only when one subscriber holding one copy of published news meeting another subscriber without that message, the epidemic transmission happens, where the holding one will create one more copy and transfer that copy to another subscriber. So with this limited epidemic routing, the copy number can be increased in the transmission process.

However, there is still one more problem how PSD can keeps the delivery rate and latency requirement of Pub/Sub applications, if the number of subscribers is very low. The answer lies in the third change of PSD to Spray&Wait routing. PSD introduce a new role of "helper" for non-subscribers in Pub/Sub applications that some non-subscribers will operate in limited epidemic routing mode like the subscribers under two conditions. The first condition is that the non-subscriber only holds one copy of published news message; otherwise, it can directly transmit half number of its copies to the subscriber according to Spray&Wait routing rule. The second condition is the density of subscribers. Nonsubscribers record the recent T encounters to estimate the density of subscribers. If the proportion of subscribers in T encounters is less than a certain rate, the node changes its status to be a helper; on the contrary, if more than that rate, the node will change its helper role back to ordinary non-subscriber role. The appropriate rate plays an important role in keeping the delivery rate and latency, which will be carefully evaluated through simulations.

As a conclusion, PSD is a one-to-many routing protocol, which combines Spray&Wait and epidemic routing to fulfill Pub/Sub applications. Epidemic routing only happens on certain subscribers and helpers in order to increase the copy number in message delivery process. With such kind of epidemic routing, the source can inject certain number of copies only according to subscribers' number.

2.3 Example of PSD

In order to illustrate PSD clearly, we give an example in Fig. 1 to describe the operating scenario of PSD. Figure 1 shows a snapshot of a Pub/Sub application in a DTN system.

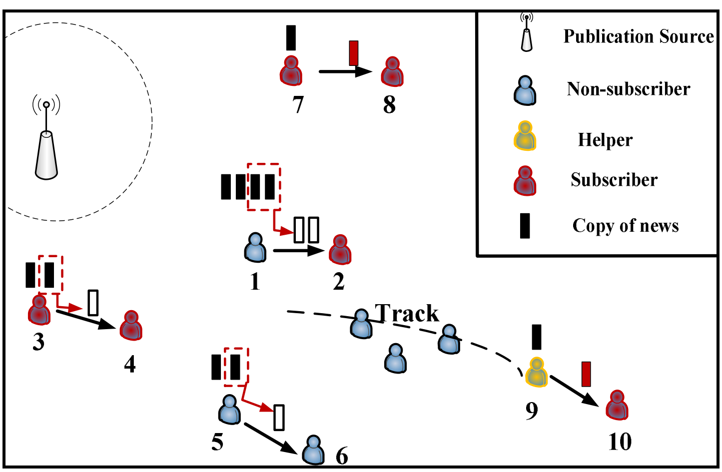


Fig. 1. Example of PSD operating process. Rectangles represent copies conducted by the publication, the black ones is original copies; the red ones represent the copies conducted by helpers or subscribers; while, the white is the original black ones being transferred.

In PSD, mobile nodes may send request message to subscribe interesting news at any time, which is labeled as blue person in Fig. 1. The subscribe message will be transferred through one-to-one routing protocol like Spray&Wait. After sending out the subscribe message, such node changes into a subscriber labeled as red person in Fig. 1. And subscribers can send quit message to cancel the current subscription at any time. When it sends out quit message, it will turn into nonsubscriber again.

The publication source creates new message periodically. Certain number of news copies will be injected into the network through Spray&Wait protocol when there are some nodes passing by. The initial number of news copies is determined according to the count subscriber number on publication source. Figure 1 shows the publication source still has 8 copies of the current news to be transferred through Spray&Wait protocol.

When some node holding more than one copy of the current news, it will transfer half of copies through Spray&Wait protocol. As shown in Fig. 1, the copies transferring between node 1 and node 2, node 3 and node 4, node5 and node 6 belong to Spray&Wait protocol.

Limited epidemic transmission happens when a subscriber carrying one copy or a helper meets another subscriber. The transferring between node 7 and node 8 in Fig. 1 shows the epidemic transmission between two subscribers. Node 9 is a nonsubscriber with the last copy of current news, which changes into helper (labeled in yellow) after meeting several nonsubscribers. Node 9 will conduct epidemic transmission when it meet node 10, which is another subscriber.

3 Simulations

This section first introduces the simulation environment, then illustrates the performance parameters and presents the results in details. We used the Opportunistic Network Environment simulator (ONE [8]) as our simulator. The environmental parameters are shown in Table 1, including node number, movement speed, communication range, mobility model, and storage capacity. The timeliness of published news is half an hour, so the source node counts the number of subscribing requests and broadcasts news message every half an hour. Other nodes can send subscribe requests or cancel messages at any time.

Table 1. The environmental parameters used in this experiment

parameter	number	speed (m/s)	range (m)	mobility model	storage capacity (M)
Group1	1	--	10	fixed node	50
Group2	40	2.7-13.9	10	ShortestPathMapBased	50
Group3	40	7.0-9.0	10	ShortestPathMapBased	50
Group4	41	7.0-10.0	10	MapRoute(tram3.wkt)	50
Group5	2	7.0-10.0	10	MapRoute(tram4.wkt)	50
Group6	2	7.0-10.0	10	MapRoute(tram10.wkt)	50
Group7	50	8.0-10.0	10	MapRoute(tram10.wkt)	50
Group8	75	6.0-8.0	10	ShortestPathMapBased	50

We introduce several labels in the simulations. S represents the number of subscribers which the source has counted in current time. L is the initial value of news copies that will be injected into the network by the source. T represents the encounter number of unsubscribe nodes in order to determine the density of subscribers in the network. Subscriber rate (SR) is the threshold for the unsubscribed node to change to helper. If one unsubscribed node holding only one copy of some news find that the proportion of subscribers met in T encounters is low than SR, it will make a conclusion that the density of subscribers on such news is too low and change itself into "helper" role. We repeat the simulations by using different values of above four parameters to evaluate the performance of PSD.

In our simulations, four metrics are evaluated and defined as following:

Delivery rate (DR): DR is defined as the proportion of subscribers that successfully received the news in current timeliness of that message.

Average Latency (LA): LA is defined as the average latency of all news messages successfully delivered. We count it in seconds.

Cost: Cost is defined as the ratio of the message relayed to the message successfully received by the subscribers.

DR/Cost (DRC): DRC is defined as the ratio of DR to Cost, which represents the tradeoff between delivery rate and cost.

For the first simulation scenario, we chose T=15 to statistic the proportion of subscribers. We set L/S= 20%, 25%, 33.3%, 50%, 100% and conduct five groups of experiments. In each group, we further chose different SR values as 0%, 10%, 20%, 30%, and 40%. We compare the performance results with original Spray&Wait protocol in Fig. 2, which shows all the results of PSD are better than Spray&Wait routing.

Figure 2(a) illustrates the results on delivery rate, which first shows that high threshold of subscriber rate leads to high delivery rate. Because more unsubscribed nodes will become helpers when the subscriber rate is high, the actions of limited epidemic routing between helpers and subscribers will increase. And the delivery rate has not clear increase when the subscriber rate is higher than 20%. For the same value of subscriber rate, larger L/S value, larger delivery rate. This is directly benefited from more copies injected into the network.

Figure 2(b) shows the results on cost. It shows that the cost gets larger when the subscriber rate gets larger. This conclusion is somehow not intuitive. The key is the action of limited epidemic transmission of helpers, which only happens when a helper meets a subscriber. All such limited epidemic transmissions are effective actions, which will help in decreasing cost. If the subscriber rate is very high, e.g. 100%, every unsubscribed node will become helpers, which will surely help decrease cost, but will cost the cache space of such nodes. And the cost has not clear decrease, when SR is over 20%, there is no need to further increase SR. Figure 1(b) also shows that large L/S leads to high cost.

Figure 2(c) shows the results on average delivery latency. It shows that the latency gets lower when the subscriber rate gets larger or L/S gets larger. As the timeliness of the news is of 30 minutes, all the average latency values are lower than that value. So in our simulations, every result keeps the timeliness. Moreover, SR=20%, it is still an inflection point for average latency.

In Fig. 2(c), we can calculate that the difference between maximum and minimum on average latency is about 300s, no more than 5 minutes; therefore, we focus on the ratio of delivery rate to cost in Fig. 2(d). It shows CDR of L/S=50% is higher than other L/S values, so L/S=50% achieves better tradeoff of delivery rate and cost. Moreover, CDR gets its maximum value for L/S =50%, when SR=20% in our simulation environment.

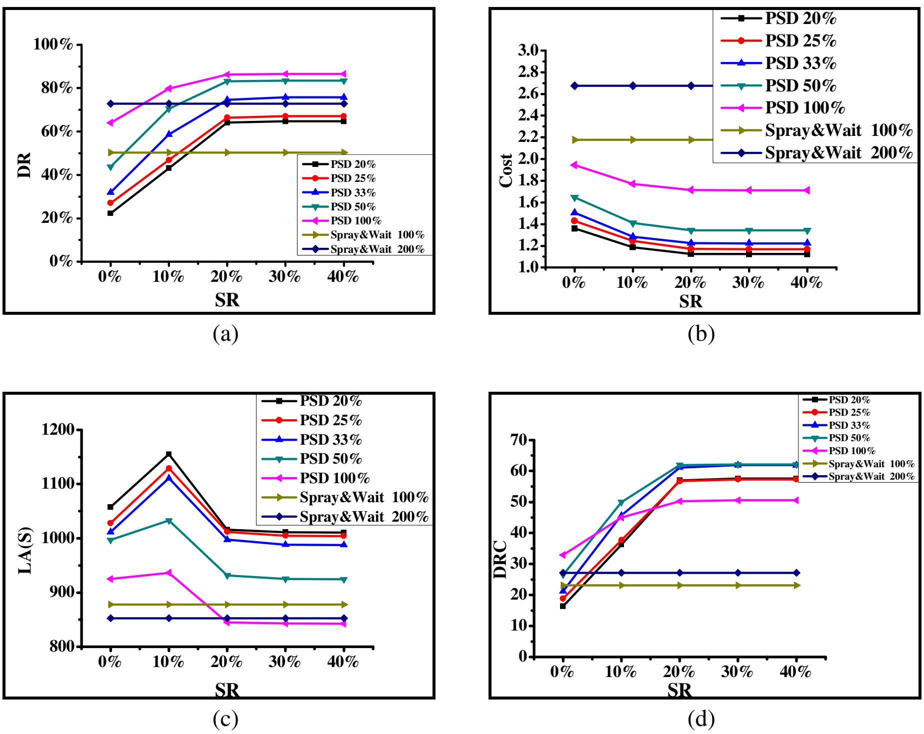
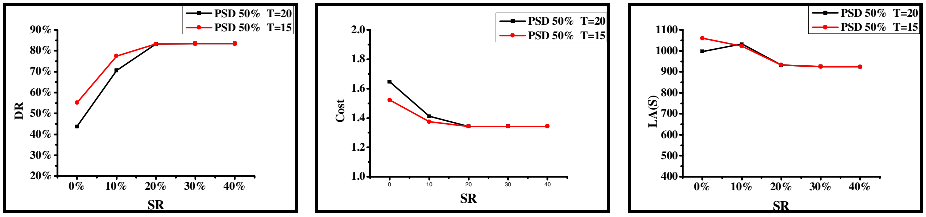


Fig. 2. Simulation results of five groups on different values of SR and L/S (a) delivery rate (b) cost (c) latency (d)delivery rate/cost (the percent number in legend presenting the value of L/S)

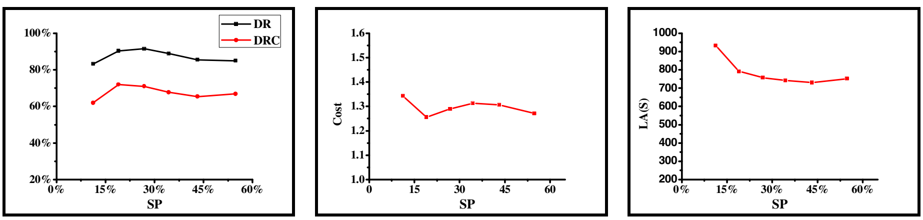
In another simulation, we evaluate the impact of parameter T. We compare two groups (T=15 and T=20) with Spray&Wait routing. In Spray&Wait routing, we let the initial value L of news copies to be one and two times of the subscriber number. The result is shown as in Fig. 3. No matter L/S=100% or 200%, the performance in Spray&Wait routing is far lower than PSD. And the result difference between two T values is not that clear, especially when subscriber rate is over 20%. So we can conclude that the encounter interval T has little impact on the performance of PSD.



(a) (b) (C)

Fig. 3. Results of PSD on T=15 and T=20(L/S=50%) (a)delivery rate (b)cost(c)latency

We further evaluate the impact of subscriber quantity under the best configuration of L/S=50% and SR=20%. Fig. 4 depicts that the delivery rate, average latency and cost almost are the same under different proportions of subscribers. X axis presents the proportion of subscribers to all nodes in the system, labeled as SP (subscriber proportion).This kind of stability comes from the impact of limited epidemic transmission of helpers, which make up to the quantity of such routing only between subscribers. This confirms the feasibility of PSD: the performance stays stable, no matter how many subscribers there are.



(a) (b) (c)

Fig. 4. Simulation results of CD, CDR, Cost and LA on different proportions of subscribers

4 Conclusion

Pub/Sub applications bring new challenges to DTN routing design. Traditional one-to-one routing protocol cannot solve Pub/Sub problem efficiently. This paper proposed the combination of Spray&Wait and Epidemic routing to solve one-to-many routing problem of Pub/Sub applications in DTN. The simulation results confirm that the proposed PSD protocol achieves better performance in delivery rate, cost and latency than Spray&Wait and can realize the tradeoff between delivery rate, cost and latency in Pub/Sub applications.

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