Poster: Modeling the Performance of Routing in Heterogeneous Delay-tolerant Networks*

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ABSTRACT

This paper investigates the heterogeneity of delay-tolerate networks (DTNs) by considering that among regular nodes some infostations are equipped with large-capacity buffer and connected by high-speed links to form an infostation system. We analytically model epidemic routing behavior of such DTNs using extended Susceptible-Infectious-Recovered model. Specifically, closed expressions for the number of infectious nodes with varying time, Cumulative Distribution Function (CDF) of packet delivery delay and CDF of infostations infected time are derived. Based on extensive numerical results, the impact of transmission range and inforstation number on the network performance is revealed.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless Communication; C.2.2 [**Network Protocols**]: Routing protocols.

Keywords

heterogeneous delay-tolerate networks;routing;Infostation

1. INTRODUCTION

Modeling the performance of routing in heterogeneous delay tolerant networks (DTNs) is challenging since it must handle amount of different nodes with wide characteristics coexisting together. However, with the rapid growth of different types of users (in the terms of coverage range, transmission power, buffer space and bandwidth), heterogeneous DTN is a trend in the further. Thus, to provide a guide for this work, this paper focuses on exploiting the influence of infostation system on DTNs.

Infostation was originally proposed in [1] to improve the performance of wireless networks by providing strong radio signal quality to small disjoint geographical areas. [2] extended its concept by integrating it with the ad hoc networking technology and applied the Shared Wireless Infostation Model to a biological information acquisition system. However, these infostations were only seen as the destinations of messages so as to gather information from mobile nodes, which are different from our proposed infostation system.

In this paper, each infostation is equipped with two or more communication interfaces. One interface with low data rate and small coverage, is used for communicating with regular nodes. The other interface, denoted by high-level interface, is used for data sharing between infostations. It could be wired link such as optical fiber or wireless connection such as 4G. Consequently, we assume that as soon as a infectious node touches any infostation, all the other infostations are infected.

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2. SYSTEM MODEL AND ANALYSIS

We model the infostation-based epidemic routing [3] through extending the idea behind Susceptible-Infectious-Recovered (SIR) model [4]. We consider a network consisting of N+1 mobile hosts moving in a closed area and M pre-arranged infostations. We assume the inter-meeting time of any pair of regular nodes in an exponential random variable with rate β and the inter-meeting time of a regular node and any infostation in an exponential random variable with rate μ [2]. Nodes that have a copy of the message are called *infected nodes*. On the contrary, nodes that do not have a copy the message, but can potentially store and forward a copy, are called *susceptible nodes*.

In epidemic routing, whenever a susceptible node makes contact with an infectious node, the total number of infectious nodes I(t) increases, while the total number of susceptible nodes S(t) decreases. The infection rate, also the changing rate of I(t), can be expressed by

$$I'(t) = \frac{dI(t)}{dt} = \beta I(t)S(t) = \beta I(t)[N - I(t)] \tag{1}$$

Let T_d be the packet delivery delay. Cumulative Distribution Function (CDF) of T_d is denoted by P(t), $P(t) = Pr\{T_d < t\}$. Suppose that the destination has not received any copy of a message at time t. At time $t + dt$, the destination gets infected with rate $\beta I(t)dt$, so

$$\begin{aligned} P(t+dt) - P(t) &= [1 - P(t)]\beta I(t)dt \\ P'(t) = \lim_{\Delta t \to 0} \frac{P(t+\Delta t) - P(t)}{\Delta t} &= \beta I(t)[1 - P(t)] \end{aligned} \tag{2}$$

with initial I(0)=1 and $P(0) = p_c(r)$. $p_c(r)$ is the probability of a destination being placed within range of the source (denoted as r) at time 0 and it is approximate equal $\pi r^2/A$. A is the area. The solutions denoted as $I_o(t)$, $P_o(t)$ are

$$I_o(t) = \frac{N}{1+(N-1)e^{-\beta N t}}, P_o(t) = 1 + \frac{N(p_c(r)-1)}{e^{\beta N t}+(N-1)} \quad (3)$$

Supposed that, at time t_i, the infostation system is infected with probability $p_I(t_i)$. Obviously, the process of infecting the infostation system is similar to the process of infecting the destination. The only difference is the initial condition that $p_I(0) = 1-(1-p_c(r))^M$, which is the probability of any of M infostations being placed within range of the source at time 0. As a result, referring to (3) we take

$$\begin{aligned} p_I'(t_i) &= \mu I(t_i)(1-p_I(t_i)) \\ p_I(t_i) &= 1-(1-p_c(r))^M\left(\frac{N}{e^{\beta N t_i}+(N-1)}\right)^{\frac{\mu}{\beta}} \end{aligned} \quad (4)$$

Before the infostation system is infected, $I(t)$ is same as $I_o(t)$. After it is infected at time t_i, $I(t)$ changes under two circumstances: 1) a susceptible node makes contact with a infectious node; 2) a susceptible node makes contact with a infected infostation. Let $w(t,t_i)$ denote the number of infected nodes at time t under the event that infostation system are infected at t_i. Namely, for $t > t_i$,

$$w'(t,t_i) = \beta w(t,t_i)[N - w(t,t_i)] + \mu M[N - w(t,t_i)]. \quad (5)$$

Solving (5) with initial condition $w(t_i,t_i) = I_o(t_i)$, we arrive at $w(t,t_i) = \frac{a\beta N e^{\beta N t} - \mu M e^{-\mu M t}}{\beta(a e^{\beta N t} + e^{-\mu M t})}$. where a is a constant and $a = \frac{\mu M(N-1)e^{-\beta N t_i} + \mu M + N\beta}{N(N-1)\beta e^{\mu M t_i}}$. Therefore,

$$I(t) = \begin{cases} I_o(t) & t \le t_i \\ w(t,t_i) & t > t_i \end{cases}. \quad (6)$$

Note that the probability that $I(t)$ equations $w(t,t_i)$ is $p_I(t,t_i)$. Thus the average number of the infected nodes after bringing in the infostation system is

$$\begin{aligned} \hat{I}(t) &= \int_0^{+\infty} p_I'(t_i) I(t) dt_i \\ &= \int_0^t p_I'(t_i) w(t,t_i) dt_i + I_o(t)(1-p_I(t)). \end{aligned} \quad (7)$$

The same derivation may be easily adapted to $P(t)$. we have

$$\begin{aligned} P(t) &= \begin{cases} P_o(t) & t \le t_i \\ v(t,t_i) & t > t_i \end{cases} \\ v'(t,t_i) &= \beta w(t,t_i)[1 - v(t,t_i)] + \mu M[1 - v(t,t_i)]. \end{aligned} \quad (8)$$

with initial condition $v(t_i,t_i) = P_o(t_i)$ and

$$\begin{aligned} v(t,t_i) &= 1 + \frac{(p_c(r)-1)(\mu M + N\beta)}{\beta(N-1)(a e^{\mu M t + \beta N t} + 1)} \\ \hat{P}(t) &= \int_0^t p_I'(t_i) v(t,t_i) dt_i + P_o(t)(1-p_I(t)) \end{aligned} \quad (9)$$

2.1 Numerical Results and Discuss

Fig.1-2 illustrate the message diffusion process in the time spans [0,300s] when $N = 20 \sim 120$, $\beta = 0.0001r$, $\mu = 0.001r$ and $A = 1200m \times 1200m$. The number of infostations and transmission range have a huge effect on network performance. As the number of infostations(M) increases, the message spreads more fast and the expected delay($E[T_d]$ is $\int_0^\infty (1-\hat{P}(t))dt.$) decreases to a stable value as plotted. The expected delay under M=5 is very close to that under M=9 because when the number of infostations rises to a threshold value, it would no longer improve network connectivity. Same observations can be obtained regarding the increasing of transmission range.

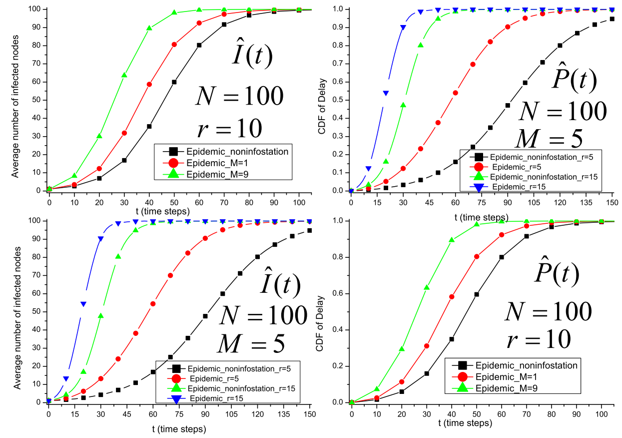

Figure 1: Infected nodes and CDF of delay

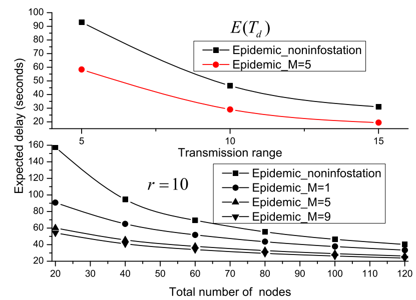

Figure 2: Expected delay

3. CONCLUSIONS

In this paper, an extended SIR model is presented to analyze epidemic routing with infostations. It follows that configuring the reasonable number and transmission range is of great importance when designing the infostations system in DTN. Our proposed analysis could help to determine the optimum value range of these two parameters. Our model can also be applied to other infostation-based routings.

4. REFERENCES

[1] D. Goodman, J. Borras, N. B. Mandayam, and R. D. Yates. Infostations: A new system model for data and messaging services. In *IEEE VTC 1997*, pages 969–973.

[2] T. Small and Z. J. Haas. The shared wireless infostation model: a new ad hoc networking paradigm. In *ACM MOBIHOC 2003*, pages 233–244.

[3] A. Vahdat, D. Becker, et al. Epidemic routing for partially connected ad hoc networks. Technical report, Duke University, 2000.

[4] X. Zhang, G. Neglia, J. Kurose, and D. Towsley. Performance modeling of epidemic routing. *Computer Networks*, 51(10):2867–2891, 2007.