# Optimal Packet Length in Delay-Tolerant Networks under Mobile-to-Mobile Fading Channel

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**Abstract.** The performance of Delay-Tolerant Networks (DTN) is deeply affected by the node mobility and time-variant wireless channel, by which the joint influence has not been investigated in depth. We analyze the optimal packet length to maximize the effective data throughput, measured by the time spent in successfully transmitting payload data with constant bit rate (CBR) during a given period, by jointly considering the impact of node mobility and wireless channel. Based on a designed simulation model which resembles the environment of mobile nodes under mobile-to-mobile fading channel, we formulate a packet length optimization mechanism to resist packet loss due to channel fading and improve the efficiency of data transmission between mobile DTN nodes, which makes significant sense in multi-hop DTN communication. Theoretically optimal packet lengths for nodes under both environment with fixed velocity and the Random Waypoint (RWP) mobility model with variable velocity are thoroughly deduced and validated by simulation results.

**Keywords:** mobile delay-tolerant networks, effective data transmission, optimal packet length, mobile-to-mobile fading channel model.

## 1 Introduction and Related Works

The application and performance of mobile Delay-Tolerant Networks (DTN) have attracted increasing attention from plenty of researchers in multiple backgrounds, like wireless communications, computer science, social science and so on. Because of DTN's huge potential for connecting wireless devices in extreme environment and delay-tolerant ability in emerging communication services or patterns. It is recognized that the performance of DTN is constrained mainly by two fundamental factors, node mobility and the time-variant wireless channel conditions, to which many research efforts have been thrown to overcome, including efficient routing algorithms, more accurate mobility models and more intelligent transmission techniques. The mobility of nodes impacts the performance

H. Qian and K. Kang (Eds.): WICON 2013, LNICST 121, pp. 55–64, 2013.

of DTN by preventing long-playing contact duration between transmission pairs and thus, bringing the unavailable end-to-end connections in the network perspective. Meanwhile, in the transmission layer, the time-variant wireless channel will influence the network performance by deep fading, path loss and interference, among which we consider the effect of channel fading in this paper.

When considering the node mobility, many research efforts have been thrown to study how to make full use of each contact duration, since locations of each communication node pair under DTN environment change real-timely therefore their mutual contact duration can be transient. [1] concentrates on improving the efficiency of data replication in DTN by establishing convex optimization problem under the premise of the awareness of contact duration. However, the accurate duration of contact is actually difficult to be obtained. [2] further considers the mutual probing delay that curtails the actual communication link time of nodes, providing a framework to compute the optimal contact-probing frequency under energy limitations and adjusting the probing frequency according to the contact rate of nodes, which can be regarded as an additional study of [1]. C. Lin et al. [3] revise the probabilistic routing scheme named *PRoPHET* in social-based DTN by considering contact duration of nodes as an important criterion for selecting next-hop relay in multi-hop DTN communication. However, these above works are blind to the fading condition of communication channels, which makes the channel intermittent, impacts the effective transmission time between mobile DTN nodes, and moreover, causes significant packet loss, when they are within their mutual transmission range. As to the channel fading in wireless networks, several related works should be reviewed. W. Song et al. [4] study the packet loss condition under the environment of 802.11 WLANs and establish theoretical packet error model which considers both impact of channel fading and packet collision. In this work, an adaptive packetization mechanism is proposed to improve the throughput of WLANs. K. Jayaweera et al. [5] propose a sensor deployment problem in fixed wireless sensor network (WSN) under Rayleigh fading channel model, in which Bhattacharya error probability is employed as the target of optimization and the optimal length between each sensor node and the fusion center is obtained.

However, we note that the environment of mobile DTN is quite different from that of WLANs and WSN in many aspects, such as frequent node mobility and sparse node density, thus calls for a appropriate fading model to describe the mobile-to-mobile channel condition of DTN. As far as we know, there are few works considering the influence of channel fading on the performance of mobile DTN nodes, which is our main contribution in this paper. Mobile-to-mobile fading channel [6] is a commonly used model to characterize the communication channel between mobile units, under which channel condition alternates between fading duration and non-fading duration [7]. The fading characteristics in mobile-to-mobile channel model is deeply affected by the velocities of both transmitter and receiver, meaning that it is a proper channel model for mobile DTN communication. Under such fading environment, data transmission between mobile DTN nodes will encounter considerable new problems, especially in how to improve the transmission efficiency.

Our main contribution is to choose the proper or optimal packet length that could balance per packet inherent redundancy and retransmission cost, thus maximizing the effective data delivery throughput between mobile DTN nodes under mobile-to-mobile fading channel, by assuming that each packet will be lost if encountering channel fading during its transmission and then calls for a retransmission. In this paper, we present the theoretically optimal packet length, which is verified by simulation results, under given mobile DTN communication environment with mobile-to-mobile channel fading and certain mobility model, with fixed or variable node velocity.

## 2 Problem Formation

We assume that communication nodes move within a given square area under Random Waypoint (RWP) mobility model [8]. In RWP model each node is assigned an initial location within a given area (typically a square) and moves at a constant velocity $v$ to a destination (named waypoint) selected uniformly in this area. $v$ is selected uniformly from given $[V_{min}, V_{max}]$, independently of the initial location and destination. After reaching the destination, new waypoint and new velocity are reselected according to the same rule. RWP model resembles some mobility patterns in the real world.

Mobile-to-mobile fading channel is a typical channel model for communication nodes with mobility, under which the channel condition alternates between fading duration and non-fading duration. We assume that two mobile DTN nodes act as transmitter and receiver and have velocity $V_T$ and $V_R$ respectively, the average non-fading duration (ANFD) of nodes [7] within the transmission range of each other can be described as below:

$$ANFD = \frac{c}{\rho f_0 \sqrt{2\pi(V_T^2 + V_R^2)}} \tag{1}$$

where $\rho = \frac{R_{th}}{R_{rms}}$, $R_{th}$ is the system-specific threshold and $R_{rms} = \sqrt{G \cdot d^{-\alpha}}$ is the root-mean-square power of the received signal, where $d$ is the distance between nodes, $G$ is proportional to the transmitted power and $\alpha$ is propagation loss coefficient. For the sake of simplicity, we assume that the $R_{rms}$ remains constant due to the power control of transmitter, then $\rho$ can also be thought of as a constant when node distance changes within the limit of transmission range. $f_0$ is the carrier frequency and $c$ is the optical velocity. Non-fading duration represents the lifetime of a mobile-to-mobile fading channel during which data transmission can be maintained between nodes, related researches have revealed that the non-fading duration of channel is exponentially distributed [7]. When channel fading occurs and a non-fading duration is over, the transmission will be interrupted and the packet being transmitted at this moment will be lost. Similarly, a fading duration of mobile-to-mobile channel model is also exponentially distributed [7], and the average fading duration (AFD) is denoted as:

$$AFD = \frac{c(e^{\rho^2} - 1)}{\rho f_0 \sqrt{2\pi(V_T^2 + V_R^2)}} \tag{2}$$

Within a fading duration, signal envelope stays below system-specific threshold and mobile-to-mobile channel is considered as unavailable for data transmission. The inverses of $ANFD$, denoted by $\lambda_A$, is the parameter of exponential distribution which characterizes the lifetime of mobile-to-mobile channel model. Under this circumstance, data should be divided into a few packets to avoid error and packet loss due to channel fading. We assume that there is a given data service $M_0$, which should be divided into $k$ packets to be transmitted through channel:

$$M_0 = k \cdot d_0 \tag{3}$$

Each packet has the effective payload data $d_0$ as well as the inherent overhead, including packet header, inter-frame space and link-layer ACK, represented by $d_{ov}$. Then the total transmitted data is:

$$M = k \cdot (d_0 + d_{ov}) = M_0 + k \cdot d_{ov} \tag{4}$$

With given constant bit rate (CBR) for transmission, we can obtain the necessary transmission time $t_s$ for each packet:

$$t_s = \frac{d_0 + d_{ov}}{CBR} \tag{5}$$

The $t_s$ can thus be employed to denote the packet length under the background of CBR. Now we analyze the problem of retransmission: we assume that each packet will be discarded if a deep fading occurs during its delivery duration $t_s$, then after the fading duration passes, the lost packet will be retransmitted. Under the background of exponentially distributed non-fading mobile-to-mobile channel lifetime, the probability for a packet to be lost during its transmission is:

$$P_f = \int_0^{t_s} \lambda_A \cdot e^{-\lambda_A \cdot t} \cdot dt = 1 - e^{-\lambda_A \cdot t_s} \tag{6}$$

where $\lambda_A$ is the parameter of exponential distribution of non-fading duration which represents characteristics of communication channel and node mobility. When fading occurs, the average length that the lost packet has been transmitted at that moment is:

$$t_l = \tfrac{1}{P_f} \int_0^{t_s} \lambda_A \cdot t \cdot e^{-\lambda_A \cdot t} \cdot dt = \tfrac{1}{\lambda_A} - \tfrac{t_s \cdot e^{-\lambda_A \cdot t_s}}{(1 - e^{-\lambda_A \cdot t_s})} \tag{7}$$

Then the expected time spent in transmitting each packet (including retransmission cost) is:

$$EPT = \sum_{k=0}^{\infty} (1 - e^{-\lambda_A \cdot t_s})^k \cdot e^{-\lambda_A \cdot t_s} \cdot (t_s + k \cdot t_l) = \tfrac{1}{\lambda_A} \cdot \tfrac{(1 - e^{-\lambda_A \cdot t_s})}{e^{-\lambda_A \cdot t_s}} \tag{8}$$

$EPT$ thus synthesizes the impact of both inherent packet overhead and packet retransmission overhead, then we can define the $efficiency\ of\ transmission$ as the ratio of effective data per packet to $EPT$:

$$\epsilon = \frac{(t_s - t_{ov})}{EPT} = \frac{\lambda_A \cdot (t_s - t_{ov}) \cdot e^{-\lambda_A \cdot t_s}}{(1 - e^{-\lambda_A \cdot t_s})} \tag{9}$$

where $t_{ov} = \frac{d_{ov}}{CBR}$. If $\lambda_A$ and $t_{ov}$ are given, transmission efficiency $\epsilon$ is thus the function of packet length $t_s$. When $\epsilon$ obtains its maximum value, the $t_s$ is supposed to be optimal. We can easily find that the first order derivative of $\epsilon$ equals zero when:

$$1 - e^{-\lambda_A \cdot t_s} - \lambda_A \cdot (t_s - t_{ov}) = 0 \tag{10}$$

which is a typical transcendental equation that has unique solution, the $t_s$ value that satisfies (10) is the theoretically optimal solution of packet length under given circumstances, including velocities of transmitter and receiver, condition of mobile-to-mobile channel and carrier frequency. Here we set $CBR = 1Mbps$, then the effective throughput of wireless transmission according to equation (9) is:

$$T_\epsilon = \epsilon \cdot CBR \tag{11}$$

We assume that each packet has an inherent overhead of 1000bit which takes a $t_{ov} = 1ms$, $f_0 = 2.6GHz$ which is a typical carrier frequency that resembles TD-LTE and $\rho = 0.6$. Two communication nodes move at the velocity of $4m/s$ respectively. Fig. 1 describes the relationship of effective throughput and packet length, which shows an obvious and unique optimal packet size $t_s$ which resembles the result in [4] under similar assumption.

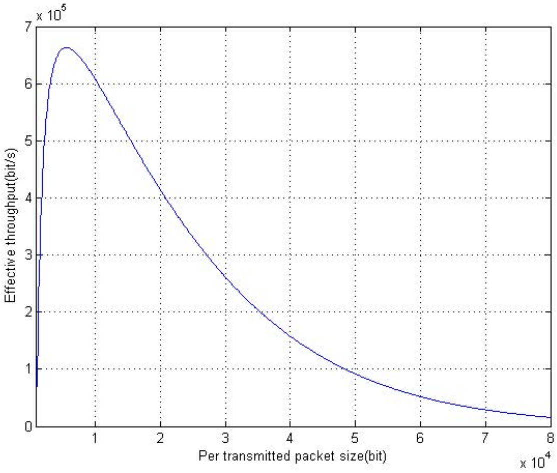

**Fig. 1.** The relationship between effective throughput and packet length

A theoretically optimal $t_s$ maximizes the effective throughput under given circumstances including the velocity of nodes, fading parameter $\rho$ and carrier frequency. However, if the environment is variable, the choice of a fixed optimal packet length which results in maximum average effective transmission throughput will be more complex. Each mobile node in RWP model will uniformly reselect its mobile velocity from given $[V_{min}, V_{max}]$ when it reaches one waypoint [8]. The change of velocity on each side of DTN communication nodes will alter the average non-fading duration of mobile-to-mobile channel according to equation (1), so the optimal packet length should maximize the mean transmission efficiency of nodes that move under RWP model.

However, the cumulative time of each velocity condition in which two communication nodes move with velocities $v_1$ and $v_2$ respectively is differently weighted, the weights are determined by the appearance probability of velocity condition $(v_1, v_2)$, the average contact frequency (i.e., the frequency that they move into each others' transmission range) of mobile nodes under RWP model which move with $v_1$ and $v_2$ respectively and the mean duration of each contact. We notice that the velocity of RWP mobile nodes is uniformly chosen from $[V_{min}, V_{max}]$ at the waypoint and each waypoint is uniformly chosen from given area, so the appearance probability of each velocity condition $(v_1, v_2)$ is inversely proportional to $v_1 \cdot v_2$. [9] mentions that the contact frequency of nodes under RWP model follows Poisson distribution and the mean contact frequency as the parameter of Poisson distribution is:

$$\lambda = c_0 \cdot \frac{V_r \cdot R}{A} \tag{12}$$

where $A$ is a square area for simulation, $R$ is the communication range of nodes, $c_0$ is a constant for given actual mobility model and $V_r$ is the mean relative velocity between nodes. Obviously, only $V_r$ is variable for different velocity condition $(v_1, v_2)$, which is denoted as:

$$V_r(v_1, v_2) = \frac{1}{\pi} \cdot \int_0^{\pi} \sqrt{(v_1^2 + v_2^2) - 2v_1 v_2 cos\theta} \cdot d\theta \tag{13}$$

where $\theta$ is the included angle of $v_1$ and $v_2$. Last but not the least, the mean duration of each contact when nodes move with velocities $v_1$ and $v_2$ is also inversely proportional to their mean relative velocity. Then we obtain the weighted integral formula of the mean transmission efficiency of a pair of communication nodes, which move under RWP model with velocity chosen from $[V_{min}, V_{max}]$ respectively:

$$\overline{\epsilon(t_s)} = \frac{1}{(V_{max}-V_{min})^2} \cdot \int_{V_{min}}^{V_{max}} dv_2 \int_{V_{min}}^{V_{max}} \epsilon(v_1, v_2, t_s) \cdot \frac{c_1}{v_1 \cdot v_2} \cdot \lambda \cdot \frac{c_2}{V_r(v_1, v_2)} \cdot dv_1 \tag{14}$$

where $\epsilon(v_1, v_2, t_s)$ and $\lambda$ are the same as we described in equation (9) and (12) respectively, $c_1$ and $c_2$ are constants. Then we substitute the term $\lambda$ with equation (12), eliminating the term of $V_r(v_1, v_2)$. Equation (14) can thus be changed into:

$$\overline{\epsilon(t_s)} = \frac{1}{(V_{max}-V_{min})^2} \cdot \int_{V_{min}}^{V_{max}} dv_2 \int_{V_{min}}^{V_{max}} \epsilon(v_1, v_2, t_s) \cdot \frac{C}{v_1 \cdot v_2} \cdot dv_1 \qquad (15)$$

where $C$ is a constant. We can see that $\overline{\epsilon(t_s)}$ is a typical transcendental integral function, which can be calculated by approximation algorithm, $t_s$ is theoretically optimal when the maximum value of $\overline{\epsilon(t_s)}$ is obtained.

## 3 Simulation and Discussion

Our simulation background is set up as shown in TABLE I, under which the performance of data transmission between two mobile DTN nodes will be evaluated.

**Table 1.** Simulation settings

| | |
|---|---|
| Simulation time | 1,000,000seconds |
| Simulation area | 1000m*1000m |
| Node transmission range | 200m |
| Mobility model | Random Waypoint |
| Communication channel model | Mobile-to-mobile fading channel |
| Channel carrier frequency | 2.6GHz |
| Inherent overhead time per packet | 1ms |

Where simulation time denotes the time period during which nodes move within given square simulation area, data transmission will be initiated when the distance between nodes is no more than the transmission range. Based on given CBR, the transmission performance is measured by the total time spent in successful payload data transmission during given simulation time, which excludes both inherent overhead time and retransmission time cost. Total effective data transmission time thus reflects the data throughput.

We first verify the performance of theoretically optimal packet length calculated from given environment parameters, letting two nodes select and travel towards each destination point according to the definition of RWP model. However, nodes move with fixed and equal velocity respectively, which will not be reselected at each waypoint. This setting maintains a given mobile-to-mobile fading environment. Data transmission with the optimal packet length will be performed as long as nodes move into the transmission range of each other. Control groups which have packet lengths different from the optimal one are tested under the same environment. Results of total time spent in effective payload data transmission during simulation are shown in Fig. 2. Here $\Delta t = 1ms$, we can see that the simulation group with theoretically optimal packet length calculated in each environment outperforms other control groups, the performance of control groups decreases as their packet lengths deviate further from the optimal one, which coincides with the curve in Fig .1. The effective throughput

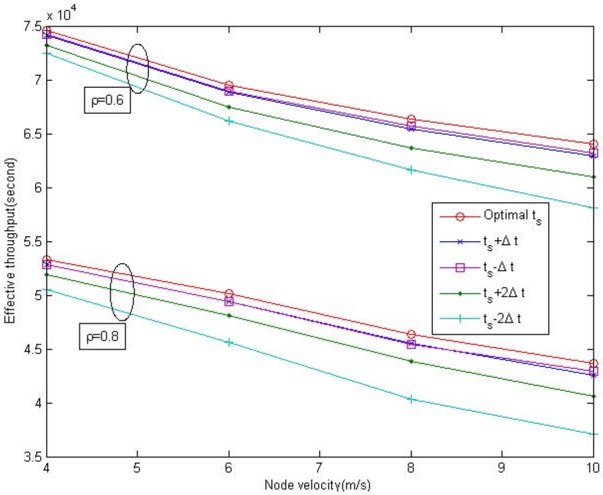

**Fig. 2.** Performance comparison of optimal packet length and other ones under the environment of given velocity

decreases faster in the groups that nodes move with higher velocities when their packet lengths deviate from the optimal one. Since equation (10) has the unique solution of $t_s$, the validity of theoretically optimal packet length is testified by the simulation.

Then we validate the fixed optimal packet length which can maximize the average effective throughput between nodes under the environment of variable velocity. We assume that communication nodes of RWP model will randomly reselect their velocity from $[V_{min}, V_{max}]$ when they arrive at each waypoint, employing the mean velocity of RWP model $\overline{V} = \frac{V_{min}+V_{max}}{2}$ as the the independent variable, where $V_{min} = 1m/s$ and $V_{max} = 2\overline{V} - V_{min}$ changes with $\overline{V}$. Simulation results of effective data transmission are shown in Fig. 3.

The simulation results validate our deduction in equation (14) and (15), proving that under the environment of RWP model with variable node velocity there still exists a theoretically optimal packet length for the transmission between DTN nodes, which results in the maximum average effective data throughput. Fig. 4 shows the comparison of theoretically optimal packet lengths deduced under the circumstances that nodes move with fixed velocity and random velocity under RWP model, respectively.

From Fig .4 we find that if $\rho$ and $f_0$ are given, the optimal packet lengths of nodes under RWP model always differ from those of nodes which move with fixed velocities that equal the mean velocities of RWP model. This phenomenon emerges from the weighted mean $\overline{\epsilon(t_s)}$ as shown in equation (15), the mean cumulative contact time will be statistically longer for a pair of nodes that move with lower velocity. So the weights of different velocity conditions are differentiated, the optimal packet lengths of nodes in RWP model are determined

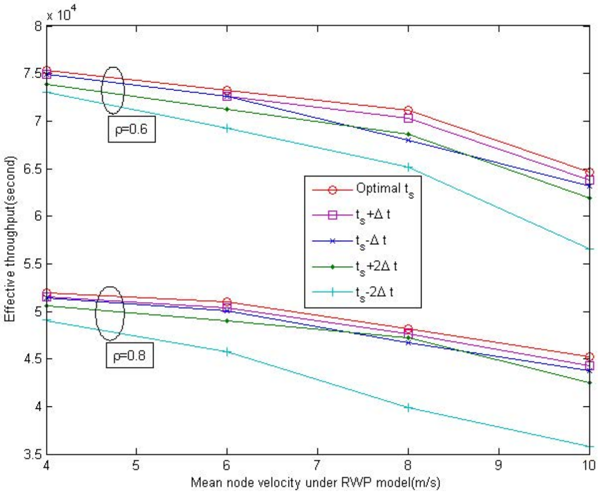

**Fig. 3.** Performance comparison of optimal packet length and other ones under the environment of RWP

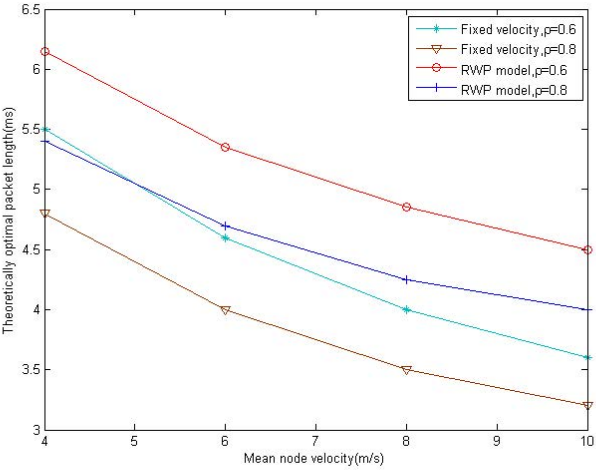

**Fig. 4.** Comparison of optimal packet length in nodes with fixed velocity and variable RWP velocity

more by conditions of low velocity and thus differ from the optimal packet lengths for nodes that move with the fixed mean velocity of RWP model.

## 4 Conclusions and Future Work

In this paper, a packet length optimization method is proposed to improve the efficiency of mobile DTN transmission, which considers the impact of mobile-to-mobile fading channel on the data transmission and formulates a thorough optimization problem. Both theoretical deductions and simulation results show that packet length will intensely affect the efficiency of data delivery in the mobile DTN under channel fading environment. A theoretically optimal packet length truly exists under both environment with fixed velocity and the RWP model with variable velocity, which can maximize the effective transmission throughput. Our future work may focus on the real-time adaptation of packet length in mobile DTN which will trace the change of environment parameters and further improve the efficiency of data transmission.

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