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TCP performance evaluation over AODV and DSDV in RW and SN mobility models*

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Abstract: This paper presents evaluation and comparison of the TCP performance in different mobile scenarios generated by Random Waypoint (RW) and Social Network (SN) mobility models. To our knowledge, TCP performance in SN mobility is discussed for the first time. The impact of AODV and DSDV routing protocols on the TCP goodput, delay and drop rate performance is also discussed. Extensive simulation results and analysis showed that TCP has better performance over AODV than over DSDV and has more stable performance in SN mobility than in RW mobility. We suggest using more mobility models, in particular, such as SN, in the evaluations of the transport layer or routing layer protocols because the mobility patterns have impacts on the protocol performance.

Key words: TCP, Social Network (SN), Performance evaluation, Mobility, Mobile ad hoc networks
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INTRODUCTION

Widely varying mobility characteristics are expected to have significant impact on the performance of routing protocols. Many previous works focused on the routing protocols and seldom discussed the impact of mobility on the transport layer protocol. On the other hand, the performance of the transport layer protocol over different routing protocols was evaluated in some previous works (Ahuja *et al*., 2000; Dyer and Boppana, 2001), but they always used the Random Waypoint (RW) mobility model to generate the node moving scenarios so that other mobility models were ignored improperly.

RW mobility model was widely used to evaluate the TCP performance in the previous works, however this model generates moving behaviors that are too general and not human-like. Camp *et al*.(2002) presented some mobility models, which also have no obvious relationships with realistic human moving scenarios. Therefore the definition of realistic mobility is a challenging work because there are no publicly available data that capture node movements from real large-scale mobile ad hoc environments.

Some new mobility models were proposed in (Bai *et al*., 2003), such as Reference Point Group Mobility Model (RPGM), Freeway Mobility Model (FW), Manhattan Mobility Model (MH). However the generation of the mobility of RPGM is heavily dependent on the initialization of the mobility of group head or leader, and the generation of mobility of FW and MH requires special given maps, such as the data on lanes and crossway layouts. TCP performance may be sensitive to these initializations.

Different from other mobility models, Social Network (SN) mobility model (Musolesi *et al*., 2004)

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is defined by the model of social network that is heavily dependent on the structures of the relationships among the people carrying the devices, and is a typical model in ad hoc networking deployment scenarios, such as disaster relief teams and platoons of soldiers, etc. Therefore, it is selected in this paper to evaluate the TCP performance in more realistic mobility models.

Considering the impact of the routing protocols on the TCP performance in given mobility model, different routing protocols are selected for evaluating TCP performance in one mobility model. As the typical proactive routing protocol and reactive (on demand) routing protocol, DSDV (Perkins and Bhagwat, 1994) and AODV (Perkins *et al*., 1999) are included in the evaluation in this paper.

The main contributions of this paper are:

(1) The evaluations and comparisons of the TCP performance in different mobile scenarios generated by different mobility models such as RW mobility and SN mobility are discussed. To our knowledge, TCP performance over SN mobility is discussed for the first time.

(2) Comparisons of the impact of different routing protocols such as AODV and DSDV in different mobility models on the TCP performance are discussed.

(3) The goodput, delay and drop rate of TCP over different routing protocols and in different mobile scenarios generated by different mobility models are discussed.

The rest of the paper is organized as follows. Related work is given in Section 2. Section 3 provides an overview of mobility models in TCP performance evaluations. Analysis of the simulations and results are discussed in Section 4. Section 5 concludes our work.

RELATED WORK

A good survey of the mobility models is provided in (Camp *et al*., 2002), but all of these mobility models are more dependent on the mathematical variants than on the modelling of the human moving behaviors. Bai *et al*.(2003) developed some tools, such as RPGM, FW and MH for mobility generation. As the initialization of the moving patterns of the group head in RPGM, and some initial maps are important for FW and MH, such as those of lanes, crossway layouts, these mobility models are not included in the evaluation for generality.

Floyed (2005) submitted an Internet draft on the metrics for the evaluation of congestion control mechanism, which provided some helpful metrics for the evaluation of TCP performance.

The survey of TCP performance problems in ad hoc networks wireless networks, cellular mobile networks was discussed in (Tian *et al*., 2005). Some TCP performance evaluations over mobile ad hoc networks were given in (Holland and Vaidya, 1999; Ahuja *et al*., 2000; Dyer and Boppana, 2001), but all the literature used RW mobility model. The latest TCP enhancements (Elrakabawy *et al*., 2005; Nahm *et al*., 2005) are not tested in the SN mobility model. The impact of multi-hops on TCP was researched in (Fu *et al*., 2005), which obtained the result that TCP performance deduction with increasing hops is due to the contention of the MAC layer, so they suggested setting the TCP congestion window limit to control the channel contention. Fu *et al*.(2002) also think the mobility of nodes is the major causative reason for the decreasing TCP performance in ad hoc networks.

OVERVIEW OF RW AND SN MOBILITY MODELS

Random Waypoint model

The RW model is the most commonly used mobility model in the mobile ad hoc networks research community. In the current network simulators (such as ns2), implementation of this mobility model is as follows: at every instant, a node moves to a random destination with a velocity chosen using a uniform or normal distribution from $[v_{min}, v_{max}]$, with v_{min} and v_{max} being the minimum and maximum allowable velocity for every mobile node respectively. After reaching the destination, the node stops for a duration defined by the pause time parameter, which is a constant value or a value in uniform distribution $[0, t_{pmax}]$, with t_{pmax} being the maximum possible pause time, after which it again chooses a random destination and repeats the whole process until the end of the simulation.

Social Network model

SN theory can be used to design more realistic mobility models for mobile ad hoc research. Musolesi *et al*.(2004) described a mobility model based on SN. It is a new two-level mobility model founded on artificially generated social relationships among the individuals carrying the mobile devices. In particular, it represents an SN using a weighted graph defining the weights associated with each edge of the network to model the strength of the direct interactions between individuals. The degree of social interaction between two persons is a value in the range [0, 1]. 0 means no interaction; 1 means a strong social interaction. A matrix $\boldsymbol{M}$ called Interaction Matrix stores the relationship information. In the matrix the element represents the interaction between two individuals. Sociability Factor (SF) is an indicator of one individual attitude towards interaction with others. A sociable host will have an SF close to 1 and a solitary one will be then characterized by an SF close to 0. The attraction intensity of a certain group towards a host is given by the sum of the interaction indicators that describe the relationships between the host and the nodes in the group.

A host belonging to a group moves inside the corresponding group area towards a goal. The clouds (groups) also move towards randomly chosen goals in the simulations space. Each group moves at a random speed, while each host moves at randomly generated different speeds. Therefore, the position of the host and group are updated as follows:

$$newX_{\text{node}\,i} = currentX_{\text{node}\,i} \pm speed_{\text{node}\,i}\Delta t \pm speed_{\text{group}\,i}\Delta t,$$
$$newY_{\text{node}\,i} = currentY_{\text{node}\,i} \pm speed_{\text{node}\,i}\Delta t \pm speed_{\text{group}\,i}\Delta t,$$
$$newX_{\text{group}\,i} = currentX_{\text{group}\,i} \pm speed_{\text{group}\,i}\Delta t,$$
$$newY_{\text{group}\,i} = currentY_{\text{group}\,i} \pm speed_{\text{group}\,i}\Delta t.$$

For the details of the SN mobility model, see (Musolesi *et al*., 2004). In the following part of this paper, RW is used to denote RW mobility model and SN is used to denote SN mobility model.

SIMULATIONS AND RESULTS

Simulation information and performance metrics

Ns2.26 (McCanne and Floyd, 1997) is used for the simulation. The tool "setdest" is used to generate the RW mobile scenarios. TCP type is Newreno in the simulations for its largest deployment in the current TCP/IP stacks. TCP sending window limit is 20 packets (Max Size Segment). There is only one TCP flow in the simulations to exclude the impact of multiple flows. The sending node and receiving node of TCP are randomly selected. TCP flow starts from 100 s and ends in 300 s, thus the first 100 s is for the warm up. The total simulation time is 300 s. The wireless signal transmission range is 250 m and the sensing range or interference range is 550 m. TCP packet length is 1000 B and ACK packet length is 40 B. Channel bit rate is 2 Mbps.

The start locations of nodes and mobile scenarios are randomly generated by the RW model and SN model. The total node number is 50. The moving plane of nodes is 1000 m×1000 m, only one dimension.

In RW mobility scenario generation, the minimum speed of host (v_{hmin}) is 1 m/s and the maximum speed (v_{hmax}) is 5, 10 or 20 m/s respectively. The moving speed of mobile nodes is randomly selected from the uniform distribution [v_{hmin}, v_{hmax}]. After the nodes reach a randomly selected destination, they will pause for a while. The pause time is also randomly selected from uniform distribution [t_{pmin}, t_{pmax}].

In SN mobility scenario generation, the host speed is in range [v_{hmin}, v_{hmax}]. The cloud (group) moves within the range [v_{cmin}, v_{cmax}]. Cloud number is 5 and the length of cloud area is 100 m. Length of the whole area is 1000 m. The seeds for the generations of 20 scenarios are 1, 2, …, 20, respectively. The values of simulation parameters for RW mobile scenario generation and SN are given in Table 1 and Table 2 respectively.

The metrics for TCP performance evaluation are:

Goodput: the amount of TCP data volume successfully received by the receiver per second.

End-to-end delay: the time from the TCP DATA packets sent out by the TCP sender to the packet received by the TCP receiver.

Drop rate: the ratio of lost TCP DATA packets over sent TCP DATA packets.

Simulation results

Figs.1a, 1b and 1c show the average goodput, delay and drop rate of TCP flow in 20 SN or RW mobile scenes over AODV or DSDV protocol with different v_{hmax}'s, such as 5, 10 and 20 m/s. The speed of mobile nodes is selected randomly from uniform distribution [1, 5], [1, 10], and [1, 20] (m/s). They are the speed distribution like a moving human, moving human and vehicle mixing, and moving vehicle, respectively.

Table 1 Simulation parameter values for Random Waypoint mobile scenario generation

Parameter	Value	Parameter	Value
Speed select	Uniform	Pause select	Uniform
Max speed	5,10 or 20 m/s	Max pause	10 s
Min speed	1 m/s	Min pause	0 s
Max *X*	1000 m	Simulation time	300 s
Max *Y*	1000 m	Node number	50

Table 2 Simulation parameter values for Social Network mobile scenario generation

Parameter	Value	Parameter	Value
Host min speed	1m/s	Cloud min speed	0
Host max speed	5,10 or 20 m/s	Cloud max speed	10 m/s
Host number	50	Simulation time	300 s
Cloud number	5	Length of cloud	100 m
Hosts in clouds	5	Length of area	1000 m

Note: seed of random number generator are 1, 2, 3, …, 20

Tables 3~5 give the average value and standard deviation of the statistics of TCP goodput, delay and drop rate performances in 20 simulation scenarios generated by each mobility model.

The later of this paper gives the analysis results. The comparison between AODV and DSDV, the comparison between RW and SN (in the case of TCP over AODV), and the comparison between different v_{hmax}'s, i.e., 5, 10, 20 m/s (in the case of TCP over AODV) are discussed. The stability of the performance is also discussed according to the STDV (Standard Deviation) value in Tables 3~5.

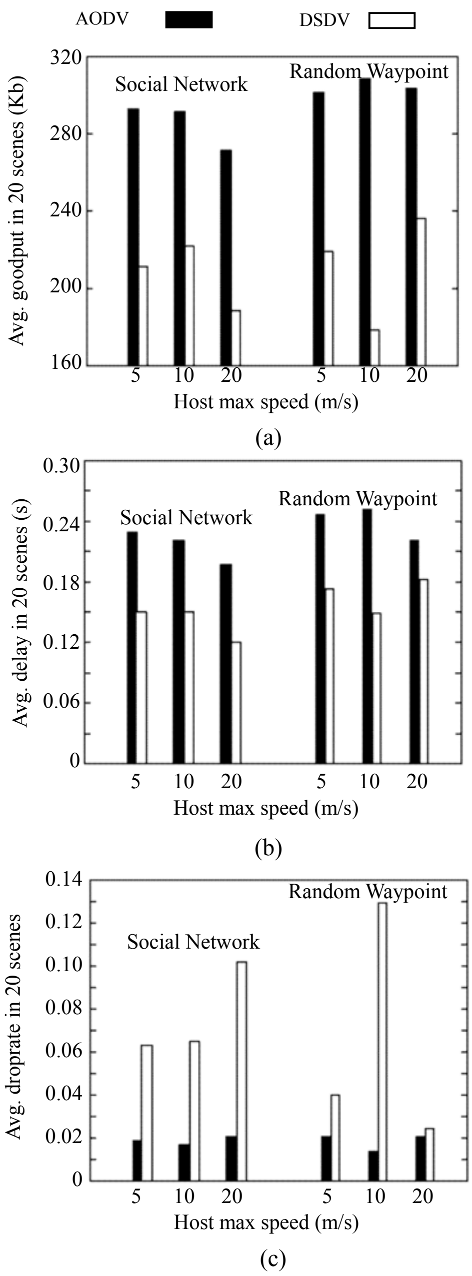

Fig.1 Average goodput (a), average delay (b), and average drop rate (c) performance of TCP in 20 SN or RW mobile scenes over AODV or DSDV protocol with different host max speeds

TCP goodput performance comparisons

Fig.1a shows that TCP over AODV has better goodput performance than TCP over DSDV in all the v_{hmax} selections and different mobility models. After checking the TCP goodput dynamics with the changing of simulation time, we found that in most scenarios of DSDV, there are some stopping phases in which TCP goodput is zero. However it seldom happens in scenarios of AODV. If the DSDV routing fails, the TCP connection will break and TCP flow will stop in the end. If the AODV routing fails, the routing information may be rapidly rebuilt and TCP flow is kept alive.

Over AODV routing protocol, TCP average goodput performance in RW mobility scenarios is a little higher than that in SN in all v_{hmax}'s. Therefore, for the evaluation of TCP performance, only using single mobility model, such as RW, to generate mobile

Table 3 Average and standard deviation of TCP goodput performance in 20 scenarios (for v_{hmax}=5, 10, 20 m/s respectivly)

Routing protocol	Social Network mobility model						Random Waypoint mobility model					
	STDV			AVG			STDV			AVG		
	5	10	20	5	10	20	5	10	20	5	10	20
AODV	116.12	102.13	123.29	292.66	291.47	271.29	176.24	139.35	121.68	301.59	308.52	303.22
DSDV	173.34	152.05	170.43	211.65	222.08	188.87	208.89	165.59	184.93	219.42	178.27	236.34

Table 4 Average and standard deviation of TCP delay performance in 20 scenarios (for v_{hmax}=5, 10, 20 m/s respectivly)

Routing protocol	Social Network mobility model						Random Waypoint mobility model					
	STDV			AVG			STDV			AVG		
	5	10	20	5	10	20	5	10	20	5	10	20
AODV	0.0500	0.0494	0.0350	0.2294	0.2212	0.1970	0.0789	0.0546	0.0504	0.2459	0.2518	0.2206
DSDV	0.0637	0.0499	0.0634	0.1495	0.1500	0.1207	0.0560	0.0649	0.0572	0.1724	0.1491	0.1823

Table 5 Average and standard deviation of TCP drop rate performance in 20 scenarios (for v_{hmax}=5, 10, 20 m/s respectivly)

Routing protocol	Social Network mobility model						Random Waypoint mobility model					
	STDV			AVG			STDV			AVG		
	5	10	20	5	10	20	5	10	20	5	10	20
AODV	0.0134	0.0088	0.0104	0.0188	0.0168	0.0204	0.0228	0.0120	0.0207	0.0205	0.0140	0.0204
DSDV	0.1486	0.2207	0.2582	0.0630	0.0648	0.1021	0.0600	0.2586	0.0354	0.0403	0.1293	0.0244

scenarios is not convincing and inclusive. Since the SN model is more similar to human mobile behaviors, we suggest that it is better to use SN mobility model for evaluation of TCP performance for the communities researching performance evaluation in wireless mobile ad hoc networks.

Over AODV routing protocol, in RW mobility TCP average goodput changes a little in different v_{hmax}'s, which means both in human motion and vehicle motion, the goodput performances are maintained well. However over AODV in SN mobility, the TCP average goodput is smaller when v_{hmax} is larger. It confirms some observations that the moving speed of nodes is the major factor impacting the TCP performance (Fu *et al*., 2002). We argue that using SN mobility model yields more realistic and creditable evaluation of the TCP goodput performance over AODV than using RW mobility model.

Table 3 shows that TCP over AODV has lower value of STDV and higher value of AVG (average) than TCP over DSDV in all the scenarios. Therefore, we can draw the conclusion that TCP over AODV has not only more stable goodput performance but also better goodput performance than over DSDV in all the simulation scenarios, no matter what v_{hmax} is and the node mobility model is.

Over AODV routing protocol, STDV value in SN mobility is lower than that in RW mobility in most cases of different v_{hmax}'s. Therefore, over AODV protocol, TCP in SN is more stable than in RW. Its property becomes an additional reason for our suggestion to use SN mobility model to evaluate the TCP performance over mobile ad hoc networks.

Over AODV routing protocol, in RW mobile scenarios TCP has more stable goodput performance at high v_{hmax} than in low v_{hmax} according to the STDV values. In SN mobile scenarios, the v_{hmax} of 10 m/s has the best stable goodput performance. Therefore, the speed of nodes has some impacts on the TCP goodput performance. We suggest that in future evaluation of TCP performance over mobile ad hoc networks the different v_{hmax}'s should be considered and tested.

TCP delay performance comparisons

Because the statistical data only counts the delay values in successful TCP transmission phases, not including the TCP idle phases, in Fig.1b, TCP over DSDV has lower average delay. It is reasonable as the time for requesting for routing information is shorter in DSDV than that in AODV. Actually, analysis of the trace file shows that the idle time of TCP over DSDV is much longer than that over ADOV, so if counting the idle time, the average delay of TCP over AODV is lower than that over DSDV.

Over AODV routing protocol, TCP delay performance in RW mobility scenarios is worse than in SN no matter what the v_{hmax} is. Similar to results of the previous analysis of TCP goodput performance, this result also shows that the evaluation of TCP performance, using only single mobility model, such as RW, to generate mobile scenarios is not convincible and inclusive. We suggest that it is better to use SN mobility model to evaluate TCP performance in wireless mobile ad hoc networks.

Table 4 shows that the delay performance of TCP over AODV is more stable than that over DSDV in almost all the scenarios.

Over AODV routing protocol, TCP in SN mobile scenarios is more stable than in RW mobile scenarios, no matter what the v_{hmax} is.

Over AODV routing protocol, in RW and SN mobile scenarios, TCP has more stable delay performance when v_{hmax} is higher.

The delay performance is very important to application such as web. If the waiting time is too long, the user may have no patience and thus cancel the connection.

TCP drop rate performance comparisons

In Fig.1c TCP over DSDV has much higher average drop rate than TCP over AODV. This result accords with the observation of TCP goodput and delay in previous sections. According to the whole goodput, delay and drop rate performance analysis, we can draw the conclusion that TCP has better performance over AODV than over DSDV.

Over AODV routing protocol, in SN or RW mobility model, TCP has different drop rates, but all lower than 2.1%. It shows that AODV protocol can maintain routing information effectively for the transport protocol no matter what the node mobile pattern is (SN or RW). AODV is robust in different mobility models, in other words, in different mobile scenarios. Therefore, considering the performance of AODV in SN mobility model, AODV is suitable for the application in human-like mobile ad hoc networks environments.

Over AODV routing protocol, both in RW and SN mobility scenarios, TCP has the best drop rate performance when v_{hmax} is 10 m/s. Including the observation of TCP goodput and delay performance over AODV in RW, it shows TCP over AODV has the best performance when the node has intermediate speed (v_{hmax}=10 m/s).

Table 5 shows that TCP over DSDV has very large STDV values in 20 mobile scenarios. It means drop rate of TCP over DSDV is extremely different. It accords with previous analysis that TCP performance over AODV is more stable than that over DSDV.

Over AODV routing protocol, TCP drop rate performance in SN mobile scenarios has smaller STDV value than that in RW mobile scenarios in all v_{hmax}'s. It accords with the results of previous analysis that TCP is more stable in SN than in RW.

Over AODV routing protocol, both in SN and RW mobility models, TCP drop rate performance is most stable when v_{hmax} is 10 m/s.

DISCUSSION

In summary, TCP over AODV has better performance, including goodput, delay and drop rate, than TCP over DSDV after the evaluation in both RW mobile scenarios and SN mobile scenarios.

Over AODV protocol, TCP performance, including goodput, delay and drop rate, is different in different mobility models, so the evaluation of TCP performance over mobile ad hoc networks requires consideration of different mobility models. We suggest the SN mobility model because of its stability and it is realistic and human-like.

TCP over AODV in RW or SN mobility model has different performance when v_{hmax} are different. For TCP over AODV and RW, the maximized host speed with intermediate (10 m/s) value has the best goodput and drop rate performance. For TCP over AODV and SN, the hosts with lower speed have better goodput and drop rate performance.

TCP performance is different in RW and SN mobile models. We suggest that the future evaluation of TCP performance should be done in different mobility models and different v_{hmax}'s. TCP performance is more stable in SN scenarios than in RW scenarios in different cases of v_{hmax}'s. If SN model can model well the human motion behaviors, the evaluation of TCP performance will be more creditable and small sample space (simulation scenarios) is enough.

CONCLUSION

In this work, we evaluate the TCP performance including the goodput, delay and drop rate over AODV or DSDV routing protocol in Random Waypoint mobility model and in Social Network mobility model.

Extensive simulation results and analysis showed that the TCP performance is better over AODV than over DSDV because of its higher goodput, lower drop rate and is more stable in different mobile host speed scenarios, in the scenarios generated by both Social Network mobility model and Random Waypoint mobility model.

TCP performance is more stable in the mobile patterns of Social Network mobility model than in the mobile patterns of Random Waypoint mobility model. We suggest using more mobility models, in particular, such as SN, in evaluating the performances of the transport layer protocols because the mobility patterns have impacts on the protocol performance.

The host speeds also should be considered especially if the mobility model is Random Waypoint. For TCP over AODV and RW, the maximized host speed with intermediate (10 m/s) value has the best goodput and drop rate performance. For TCP over AODV and SN, the hosts with lower speed have better goodput and drop rate performance.

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