JOURNAL OF PURE AND APPLIED MICROBIOLOGY, April 2013. Vol. 7(Spl. Edn.), p. 227-233

Human Driving Mobility Model Based Availability Evaluation for Multi-hop Vehicular Delay Tolerant Networks

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(Received: 03 March 2013; accepted: 14 April 2013)

In realistic bioenvironmental monitoring system, sensing devices may be scattered into a large area of wild and isolated field without any communication infrastructure. Due to the geographic isolation and the dynamic mobility, frequent failures and random disturbance of independent nodes, end to end fully connected path may never exist and sensing data delivery and ingestion may face great challenges in this disconnected network. VDTN (Vehicular Delay/Disruption Tolerant Network) can ingest and carry the sensing data and fill the gaps between the isolated target field and the nearest communication infrastructure via the mobility of vehicular mounted devices. It provides balance between certain delays and the probability of successful packet delivery to achieve survivability in disconnected networks. In this paper, connectivity availability evaluation model is introduced to help directed VDTN routing and context driven packet forwarding. A Driver Operation based Mobility (DOM) model is proposed to simulate the mobility of nodes in monitoring system and connectivity availability is evaluated to estimate the end to end packet delivery ratio of multi-hop networks. Deployment guidelines are given for VDTN based bioenvironmental monitoring system applications, with timeliness and performance requirements.

Key words: Vehicular network, Mobility, Delay tolerant, Connectivity availability.

As the communication technology develops, demand of information acquiring via sensor networks is boosting(Ettema *et al*., 2006). In realistic bioenvironmental monitoring system, sensing devices may be scattered into a large area of wild and isolated field without any communication infrastructure. Due to the geographic isolation and the dynamic mobility, frequent failures and random disturbance of independent nodes, end to end fully connected path may never exist and sensing data delivery and ingestion may face great challenges in this disconnected network. VDTN (Vehicular Delay/Disruption Tolerant Network) can ingest and carry the sensing data and fill the gaps between the isolated target field and the nearest[1] communication infrastructure via the mobility of vehicular mounted devices. It provides balance between certain delays and the probability of successful packet delivery to achieve survivability in disconnected networks. Dissemination of information among vehicles is a reasonable way to achieve this ubiquitous communication system. The appearance of plenty of intelligent devices equipped for short-range wireless communications enable the ubiquitous vehicular communication. Vehicular ad hoc networks (VANET) have been envisioned to be useful in transport efficiency and safety.

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However, in realistic vehicular communication systems, the connectivity quality of networks may be poor and restricted due to the dynamic mobility, frequent sleep scheduling, failure and disturbance in environment as well as accidents. End to end fully connected paths may never appear due to extremely low duty cycle of links. Most of the existing VANET routing techniques are designed for fully connected networks and would fail when end to end path connection is broken. VDTN (Vehicular Delay/ Disruption Tolerant Network) routing provides balance between certain delays and the probability of successful packet delivery. It can achieve available packet delivery in disconnected networks.

In this paper, connectivity availability evaluation model is introduced to help directed VDTN routing and context driven packet forwarding. A Driver Operation based Mobility (DOM) model is proposed to simulate the mobility of nodes in monitoring system and connectivity availability is evaluated to estimate the end to end packet delivery ratio of multi-hop networks. Deployment guidelines are given for VDTN based bioenvironmental monitoring system applications, with timeliness and performance requirements.

To get convincible simulation result, a new driving operation based mobility model is proposed to achieve smooth and reasonable trajectory of vehicles which is more similar to the realistic world. Simulation is conducted to validate the routing design. Optimal parameters configuration is achieved under certain constraints such as expected packet delivery ratio, expected communication delay, or expected energy consumption. The computation and simulation results validate the proposed methods. The research paves a foundation for VDTN to be deployed over a wider range of application.

In the remainder of this paper, we firstly describe related approaches in section 2, and then we offer driving based mobility model and connectivity availability model for VDTN in section 3. Section 4 analyzes evaluation results. We conclude the paper in Section 5 with future research tasks.

Related works

Since the truth is that persistent full connectivity is not the rule everywhere, further researches are needed in order to overcome the limited connectivity in applications with frequent disruptive scenarios. Delay Tolerant Networks (DTNs)(Cerf, 2007) are networks that enable communication suffered from sparse and intermittent connectivity, long and variable delay, high latency, high error rates, highly asymmetric data rate, and even no end-to-end connectivity exist. The DTN Research Group (DTNRG)(Scott *et al.*, 2007) was chartered as part of the Internet Research Task Force (IRTF), it proposed DTN architecture and protocol.

VANETs assume that end-to-end connectivity and differ from DTNs. As mobility and disruption is very common in VANETs, a kind of Vehicular Delay-Tolerant Networks (VDTNs)(Pereira *et al.*, 2011) is attracting more and more attentions where vehicles communicate with each other and with fixed nodes placed along the roads in order to disseminate messages. VDTNs support also extreme networks through its store-carry forward paradigm, and extend VANETs with DTN capabilities to support long disruptions in network connectivity.

Most of the problems in VDTN arise from the direction and velocity of vehicular mobility that are responsible for a dynamic network topology and short contact durations. Reliable communication subjected to unpredictable connectivity due to dynamic mobility and limited energy source has long been recognized as a difficult task. There always exists trade-off between high reliability and the fast responsiveness. One way is to maintain the connectivity to achieve highest performance and lowest delay(Zhang *et al.*, 2007; Schurgers *et al.*, 2002).The other is to maximize the probability of successful transmission at given delay.

Most of the previous works address the former issue. Many evaluation of the connectivity availability were proposed with assumption of the full connectivity without consideration of frequent disruptions and large scale delays(Zhang *et al.*, 2007). The assumption may not be true in realistic networks.

Since connectivity availability has a strong impact on the packet delivery ratio, in many research works, connectivity availability can be evaluated by measurement of packet delivery ratio and availability model is also used to estimate the end to end packet delivery ratio(Zhang *et al.*, 2007).

Paper(Chen, 2002; Zhang *et al*., 2010) offer a model of random sleep scheduling (Ocakoglu *et al*.,2006;Greenberg *et al*.,2009) based on a two state Markov process, and computed the probability of the node being available for at least k slots in n consecutive slots to estimate the packet delivery ratio of network. It doesn't evaluate the end to end packet delivery ratio in multi-hop network. In reference 12(Xu *et al*., 2008), a data forwarding method is proposed for DTN networks. The recursive equation of the delivery ratio and end to end delay is offered. Since only the data delivery within a given deadline is considered as successful delivery, the delivery ratio varies with the delay time. However the delivery ratio equation in reference 13(Yu *et al*., 2007) is time independent. It does not provide a computable formula to describe the relationship between the performance and the parameters such as duty cycle, status transition frequency and delay.

The connectivity availability is highly coupled with the mobility and activity of vehicular devices in VDTN. The mobility pattern of VANET is quite different from the random waypoint model RWP that is intensively used for ad hoc network simulations(Christian *et al*., 2003).

Classical mobility model can be catalogued into two kinds. One is synthetic model which is based on probabilistic parameters of mobility pattern. The other one is statistical model which is based on statics data gathered from realistic ingestion and investigation in real world. Most papers fall into synthetic model category. Some papers discuss routing protocols using macroscopic model where the mobility pattern is defined by average vehicle speed, traffic density, traffic flow, and net time gap. Some paper focus on the motion details of vehicles, such as individual vehicle speed, moving direction, accelerating, turning, braking etc. For statistical model, the cellular automaton approach(Chopard *et al*., 1996), combined with road patterns created based on certain maps and traffic volumes data.

In this paper we tackle with partial connectivity in VDTN network subjected to impact of mobility and disruption at the network layer. A Continuous Time Markov Chains based connectivity availability model of the VDTN is introduced to analyze the reliability of multi-hop networks. A probability formula of availability is provided in terms of speed, direction, mobility intensiveness, tolerant delay and number of hops etc. The computation and simulation show that the proposed schemes can achieve high energy efficiency and support high packet delivery ratio in low duty cycle VDTN.

Designs and models

In this section we firstly propose a human driving operation mobility model for VDTN modeling and simulation. We then present a model to evaluate the availability under unreliable and intermittent connectivity due to mobility and activity of vehicles. The formula is given to analyze the availability of VDTN with timeliness and performance requirements. The connectivity availability is defined as the probability of successful multi-hop forwarding through an N-hops path within certain tolerant delay.

The more hops the packets are relayed, the packet will be more possible to reach the target in challengeable dynamic VDTN compared with just holding the packets in buffer. In this paper, we assume that, if dissemination of packets among vehicles along multi hops path will increase the probability of successful packet delivery to the destination. The route and forward process are based on store-wait-forward manner developed in our other works on partially connected routing(Zhang *et al*., 2006). When packets are destined to a downstream neighbor who is just leaving the available communication range, packets can be buffered for latterly resumed transmission when neighbor enter the range again. This asynchronous process can be reoccurred repeatedly until the packets arrive at the destination. The process is shown as right part of Fig.1.

Fig. 1. Asynchronous Packet delivery process can fill the gap between none coverage area and infrastructure

Mobility modeling is the basis of routing protocol simulation and the performance evaluation modeling. Because the statistical model involves large scale data ingestion and processing, the modeling may be very costly. However, if synthetic model is based on artificial construction and randomized parameters, the simulated mobile activity may differ from the real scenario. If the mobility model is too arbitrary, the simulation result will be doubted.

Most mobility models are synthetic and controlled by customized motion parameters such as speed, direction etc. The parameters are randomized according to certain probabilistic process. These methods will output arbitrary and zigzag trajectory which involves emergent turning and bounced loops which can never be produced by real vehicles. This unreasonable mobility model may mislead the routing design and evaluation molding.

In this paper, we introduce Driver Operation based Mobility model (DOM) which uses the key manipulation operations of vehicle to control the moving process. This method can simulate the real physical moving action of vehicle and can output smooth trajectory such as all kinds of reasonable curves which is very similar to the real navigation trace of realistic vehicle.

There are only three main parameters of this model. One is the velocity V which is bounded to the current status of vehicle. The other is acceleration A which simulates the impact on velocity of stepping on gas pedal and brake pedal of vehicle. The last parameter is the Wheel steering angle W which simulates the steering left or right process.

Then we describe the state of the vehicle as 4 basic actions. They are stopping or parking(STOP), forwarding(ie. FWD, including backing or reversing), accelerating (accelerated forwarding, ie. ACC_F), turning(TRUN). If the V is not zero, the vehicle is on moving and the state is forwarding, accelerating and turning respectively according to different values of A and W. If the vehicle is in FWD or ACC_F states, it is going straight. If the wheel is steering and the velocity is not zero, the vehicle will run in certain curve trajectory. When the vehicle is turning (W is not 0), the accelerating action is prohibited (ERRO state).

The different combinations and time series of these key operations can describe almost all possible status and mobility of vehicle.

Fig.2, shows the state transition machine of the mobility model.

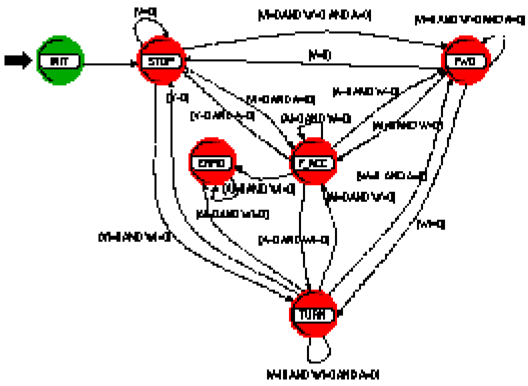
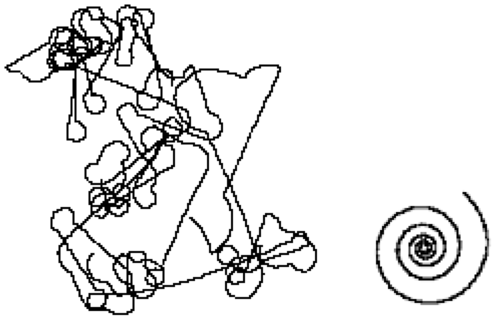


Fig. 2. Auto Machine Model of vehicle mobility process

speed and steadily varying steering angel are used to get snail curve (vortex curve). The results show



(a)Random velocity and angel (b)Steadily increased velocity and angel

Fig. 3. Simulated trajectory controlled by mobility model

Fig.3 shows the simulated trajectory controlled by DOM mobility model.

In (a), the model use random speed and random steering angle (-180^o~180^o) and can output smooth but zigzag trajectory. If the steering angel is confined to (-40^o~40^o) the trajectory will be more smooth and consistent. In (b), the steadily varying speed and steering angel are used to produce cylindrical spiral. If constant speed and angle are used it will get circle. Constant speed and steadily varying steering angel are used to get asymmetrically cylindrical spiral. Steadily varying that the proposed model can produce any reasonable and unreasonable trajectory. This model can also cover the function of most existing mobility models.

A multi-hop VDTN can be described by a triad $M = (N, P, S)$, where N is the set of network nodes, P: $N \times T \rightarrow (0, l)^2$ (l>0) is the position function and the S: $N \times T \rightarrow A$ is the status function, where A is an Boolean indicator variable, if A=1, the node should be awake and available. Function $S(u,t)$ is determined by the mobility scheduling of nodes. Suppose $G_M(t)$ is the communication graph induced by M.

$$G_M(t) = (N, E(t)),$$

$$E(t) = \{(u,v) | d(u,v) \leq R \wedge S(u,t) = 1 \wedge S(v,t) = 1\} \ldots (1)$$

$E(t)$ is the set of edges. If node u and v are within the transmission range R, and they are both available at time t, then an edge (u,v) is in $E(t)$. We assume bi-directional links, therefore if $(u,v) \in E(t)$, then .

We model wireless inter-node links (edges) in VDTN based on ON/OFF model. ON and OFF phases refer to available links statuses and unavailable links statuses, respectively. For any node u, the status of node u is independent and subjected to. In Fig. 4, the model of link is defined as follows:

1 In the ON phase, link is available,
2 In the OFF phase, node is unavailable,
3 The initial phase is ON.

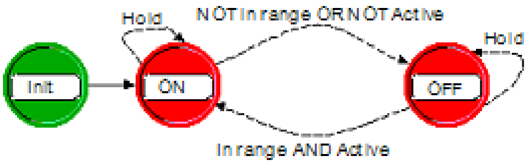


Fig. 4. Intermittently connected link model in VDTN

to OFF phase, and μ be the probability of transition from OFF phase to ON phase. The occurrence of transitions is assumed to be Poisson streams. λ and μ are determined by mobility model. The network model can be regarded a Continuous Time Markov Chains model. As a result of Markov property, the duration of the OFF phase T_{OFF} is exponentially distributed with mean $E[T_{OFF}] = 1/\mu$ and the duration of the ON phase T_{ON} is exponentially distributed with mean $E[T_{ON}] = 1/\lambda$. The duty cycle is the steady state probability of being in ON phase. Then the duty cycle, DC is $\rho/(1+\rho)$, where $\rho = \mu/\lambda$.

If the routing protocol finds a path = $v_0, v_1, v_2, \ldots, v_n$, n>1, in $G_M(t)$, data generated by a sensor node in VDTN should be forwarded to data sink over the multi-hop path from OFF phase to ON phase within a certain period of time after which the data becomes outdated. Such a requirement specifies the responsiveness of the VDTN. In this paper, we use the probability of successful packet delivery over n hops path to the destination within tolerant delay T to estimate the connectivity availability of VDTN.

The connectivity availability is the key factor of performance analysis and subjected to the routing and forwarding means. For traditional routing schemes which are designed for fully connected network, the connectivity availability E_n relies on the simultaneous availability of all the nodes along the path. The process can be represented as a multi-server closed queuing system M/M/n/n/n, where the capacity of system, number of servers and clients are n. The ON node of the path is seemed as having entered the system and OFF node as having left the system. The arrival rate is and the leaving rate is (Zhang *et al*., 2011). and are determined by the mobility model and the activity model of mobile node of VDTN. We get availability model:

$$Path_{avai} = \sum_{i=0}^{n} \left[\binom{N}{i} \cdot \frac{(\rho_m')^i}{(1+\rho_m')^n} \cdot \left(1 - \sum_{k=0}^{N-i-1} \frac{(T\mu_m')^k}{k!} e^{-T\mu_m'} \right) \right] \quad (2)$$

Where,

$$\mu_m' = \frac{\mu_m}{W \cdot C_n^2}, \quad \lambda_m' = \frac{\lambda_m}{W \cdot C_n^2}.$$

Performance analysis

We use the connectivity availability model to estimate the end to end packet delivery ratio according to computation result of the theoretical model in section 3 and compare it with the measured packet delivery ratio in a simulation of VDTN routing protocol. Results validate the consistence between the computation model and the simulation.

The simulation is conducted in network within a 1000m×1000m area with 300 mobile nodes scattered homogeneously. In the simulation study, all nodes may move and links may switch according to mobility model with the homogenous parameters. The duration of the ON phase and OFF phase follows an exponential distribution with parameter and respectively. All nodes are homogeneous with a nominal transmission range of 100m using duplex wireless radios that conform to 802.11b based wireless radios.

We randomly select 50 source nodes to generate packet traffic destined for other 50 random picked correspondents within 15 hops range. Each source generates Constant Bit Rate (CBR) traffic with average packet rate 5pps. The average packet size is 500 bytes and the fixed buffer size is 16KB. The user's tolerant delay is a controllable parameter T. The simulation time lasts for 24 hours. We assume that the sequence of router nodes is generated in the route discovery process and will not change during the simulation because the infrequent mobility of VDTN.

If packets are successfully transmitted to the destination over the multi hop path within delay of T, then we say that the application is successful. The delayed packets are dropped silently. We count the number of times the application is successful and divide it by the total number of times packets generated to determine packet delivery ratio.

For a given VDTN scenario with certain constraints such as mobility, timeliness and reliability, the methods for configuring parameters in the deployment can be provided according to the computed network model derived in the previous section. We get the optimal setting policy of the parameters such as,,, n or T, according to the formula, if the rest of conditional parameters is given. The trade-off between timeliness and duty cycle discussed in the previous section is an example of deployment policy under given energy or timeliness constrains. The result shows that The connectivity availability is dependent on the duty cycle, status transition frequency (determined by or), the number of hops and tolerant delay. We can achieve high packet delivery ratio with low duty cycle only at the sacrifice of the tolerant delay T

CONCLUSION

In this paper, we offer a systematic approach to evaluate the connectivity availability of mobile VDTN based on new mobility model. By modeling and simulation, we find that as compared to traditional model, we achieve smooth and reasonable mobility trajectory of vehicles which is more similar to the realistic world. We also investigate the variation of packet delivery ratio with respect to mobility parameters and propose optimal policy applicable to all systems, once user/ application requirements are given. This work helps to achieve routing design for VDTN with mobility, reliability, and timeliness constraints.

ACKNOWLEDGEMENTS

This work was financed by the research fund of National Natural Science Foundation of China NO. 90818006.

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