Geographic Admission Control for Vehicle Area Networks

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***Abstract*—A vehicle area network (VAN) is a local area network deployed onboard a moving vehicle, e.g., a train, bus, or a private car, to provide high-speed Internet access to the passengers. A VAN may face temporary network disconnection when the vehicle passes through challenging radio environments, e.g., deep tunnels. Such disconnections disrupt the ongoing network services causing passenger dissatisfaction. Given that tunnel locations are known, we propose to use geographical knowledge in the admission control function of the VAN to reduce the probability of service disruption. A geographic admission controller (GAC) rejects a new call request based on the vehicle's current location if it can be determined that the vehicle would enter a tunnel within a short period of time. By rejecting a new call prior to entering a tunnel, GAC reduces the probability of an admitted call to be disrupted, but it does so at the expense of increasing probability that a new request would be blocked. For a quantitative investigation of the trade-off between these two important probabilities, we propose a 2-D Markov Chain model. Using the model, we derive both probabilities as a function of the time interval from the moment the GAC starts rejecting new requests until the vehicle actually enters the tunnel. This time interval is a configurable parameter which controls both probabilities. The model is validated using simulation. Our model reveals that the disruption probability can be reduced quadratically with a linear increase in the blocking probability.**

I. Introduction

A vehicle area network (VAN) is a local area network designed to cover the interior of a vehicle, e.g., a train, bus, or a private car. Significant initiatives have been taken to standardize networking protocols which will enable permanent Internet connectivity to such VANs (see [1], and also RFC4885-to-9, and RFC 4980). Permanent VAN-Internet connectivity will allow passengers in automobiles, buses, and trains to avail the entire spectrum of network services that are currently enjoyed by residential and enterprise users. Figure 1 illustrates the generic architecture of a permanent VAN-Internet connectivity. In such networking scenarios, all communication between the passenger devices and the Internet goes through an onboard mobile router (MR) which transparently manages the Internet connectivity of the entire VAN using satellite or cellular data services. In recent years, several such commercial systems have been deployed for providing Internet services in public transport vehicles (e.g., iComera[1], 21net[2], wifirail[3]) as well as personal automobiles (Autonet Mobile[4]).

There are two major performance issues with VANs. First, the satellite (or cellular) link that connects the VAN to the Internet has a limited bandwidth (for example, the maximum data rate of the popular Inmarsat GBAN service is limited to 256 Kbps [2]). Since many applications, e.g., audio and video streaming, require guaranteed bandwidth for effective operation, connection requests from the passengers are subject to admission control at the MR. The task of the connection admission control (CAC) function is to admit a request only when there is sufficient bandwidth available in the satellite link, reject otherwise. A passenger receiving a rejection may try to connect again at a later time. Request blocking probability (RBP), i.e., the probability that a connection request is blocked due to insufficient satellite bandwidth, is an important network quality of service (QoS) parameter. Given a demand profile, the VAN operator would dimension the satellite bandwidth appropriately to keep the blocking probability below a given target.

Since a connection is admitted only when there is sufficient bandwidth to serve the connection, there is a natural expectation that all admitted connections would enjoy disruption-free service for the entire duration of the connection. Unfortunately, a second performance problem typical of VANs is the temporary disconnection from the Internet caused by the vehicle entering a geographic region where the satellite or cellular coverage is blocked for some reason. For example, a train using satellite services may face network disconnection when it enters a tunnel and not recover from the disconnection until it exits the tunnel. Depending on the speed of the train and the length of the tunnel, a disconnection can last anywhere between a fraction of a second to tens of seconds. If there are many tunnels in a train route, which is typical in many countries, the VAN would face frequent disconnections during the trip. Such unavoidable network disconnections cause disruptions to all admitted connections that are active at that time contributing to passenger dissatisfaction.

For VAN operators, service disruption probability (SDP), i.e., the probability that an admitted connection will face disruption due to network disconnection, becomes an additional QoS parameter to manage. Like the RBP, the VAN

[1] http://www.iComera.com
[2] http://www.21net.com
[3] http://www.wifinet.com
[4] http://www.autonetmobile.com

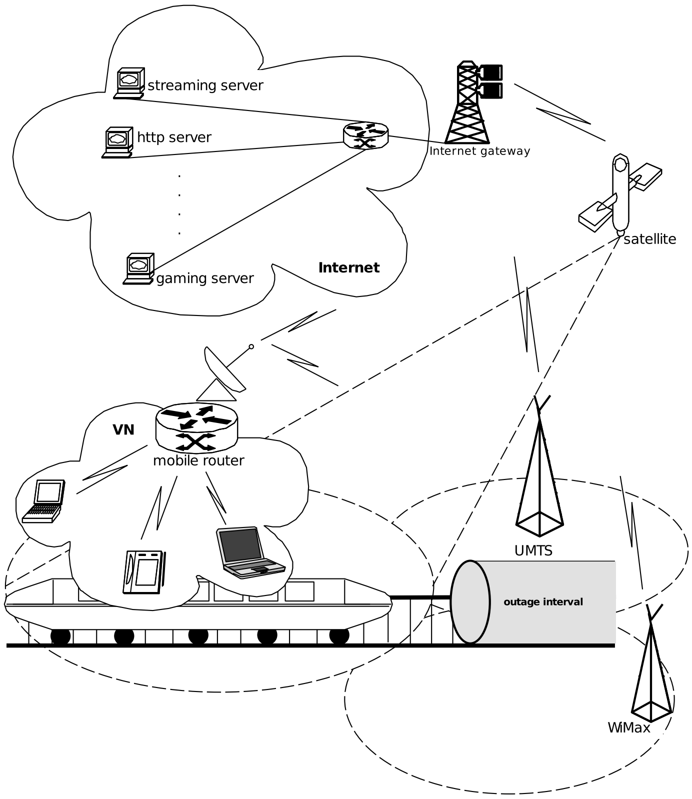

Fig. 1. Generic architecture for connecting a VAN to the Internet. The VAN faces network outage in the tunnel.

operators need to manage the SDP and keep it below a given target. Given that tunnel and current vehicle locations are readily available (e.g., through the onboard navigation unit), we propose to reduce SDP by empowering the existing CAC with these geographical knowledge. From now on, we use the term geographic admission controller (GAC) to refer to a CAC which has knowledge of both tunnel and current vehicle location. A GAC rejects a new call request based on the vehicle's current location if it can be determined that the vehicle would enter a tunnel within a short period of time. By rejecting a new call prior to entering a tunnel, GAC reduces the probability of an admitted call to be disrupted.

It is readily realized that a GAC reduces SDP at the expense of increased RBP for the VAN. The key parameter that governs these two probabilities (RBP and SDP) is the time interval (Δ) from the moment the GAC starts rejecting new requests until the vehicle actually enters the tunnel. While the operator may fail to keep the SDP under control if Δ is under-configured, CBP may be too high if it is over-configured. Therefore, to effectively manage service disruption in VANs, it is imperative to know the dependency of CBP and SDP on the parameter Δ.

We evaluate the performance of GAC using a 2-D Markov Chain model, which is validated using simulation. Specifically, we derive both RBP and SDP as a function of Δ, which allows us to investigate the trade-off between these two important probabilities. The key result revealed by the model is that, the disruption probability can be reduced quadratically with a linear increase in the blocking probability. The proposed model can serve as an effective tool for the operators of VAN to dimension their communication systems and manage the service disruptions in their networks.

The rest of the paper is organized as follows. The Markov model is presented in Section II followed by a description of the simulation designed to validate the model in Section III. Section IV presents the results obtained from the Markov Chain and the simulation experiments. Related work is reviewed in Section V. Our concluding remarks are presented in Section VI followed by a discussion of possible future works in Section VII.

II. System Model

Suppose the satellite (or cellular) link that connects the VAN to the Internet has a capacity to support S number of calls simultaneously. Let α^{-1} and β^{-1} be the mean disconnectivity (in-tunnel time) and connectivity (out-tunnel time) durations, respectively, where both these durations are exponentially distributed. Let Δ be the remaining time to enter a tunnel when GAC starts rejecting new call requests. Let the call request arrival process be Poisson distributed with a mean arrival rate of λ calls per second. Let the call (service) duration be exponentially distributed with a mean of μ^{-1} seconds. Table I summarizes these notations.

The proposed 2-D Markov Chain model is shown in Figure

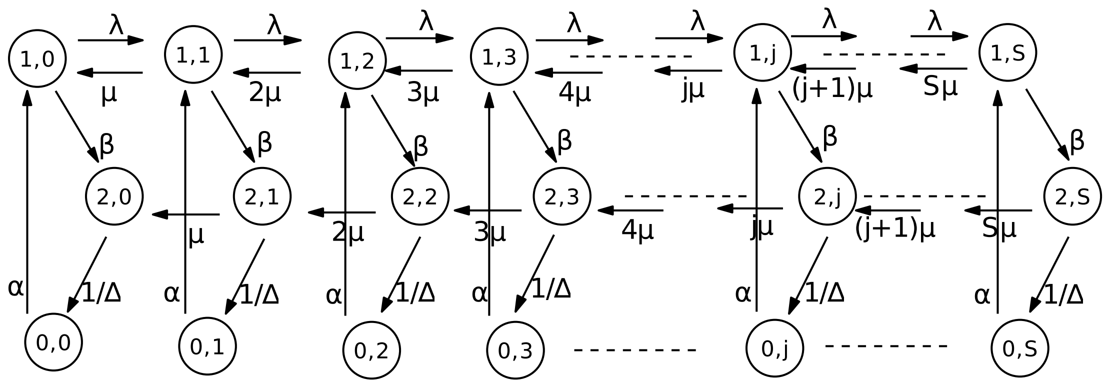

Fig. 2. Markov Chain model of *GAC*

TABLE I
SUMMARY OF NOTATIONS

	ID
α^{-1}	mean disconnection duration
β^{-1}	mean connectivity duration
μ^{-1}	mean call (service) duration
λ	call request arrival rate
Δ	GAC control parameter
$\pi_{(i,j)}$	steady state probability of state (i,j)

2. Each state in the model is represented by a duplet (i, j), where i is an integer ϵ [0 : 2] with 0 representing the VAN disconnected from the Internet (inside a tunnel), 1 connected to the Internet (outside tunnel) but more than Δ seconds away from entering a tunnel, and 2 connected to the Internet and within Δ seconds from entering a tunnel, and j is the number of on-going calls in the system. For example, state $(0, 3)$ means that the VAN is disconnected from the Internet (inside a tunnel) with three calls in the system. The probability $\pi_{(i,j)}$ is the steady state probability that the system is in the state (i, j) of the model.

Next we explain the transitions between the states. Let us start with the horizontal transitions. Given the above state definitions, it is clear that the system cannot accept any new call while in states with $i = 0$ or $i = 2$. Hence there is no right-hand transitions for the second and the third rows of the model. In the first row though, where $i = 1$, the transition rate to the right is λ, as these transitions are caused by arrivals of new call requests with a rate of λ calls per second. Similarly, rows 1 and 2 have left-hand transitions with a rate of $j\mu$, but the third row does have any such transitions. Given the definitions of α, β, and Δ (see Table I), the vertical transitions and their rates are obvious.

The equilibrium and normalization conditions of the Markov Chain model are given by Equations (1) and (2), respectively. We determine $\pi_{(i,j)}$ by solving these linear equations numerically [3].

$$\sum_{(i,j)} \pi_{(i,j)} = 1 \qquad 0 \leq i \leq 2,\ 1 \leq j \leq (s-1) \tag{2}$$

>From the model shown in Figure 2, SDP and RBP can be defined by Equations (3) and (4), respectively.

$$SDP = \sum_{j=1}^{s} \pi_{(0,j)} \tag{3}$$

$$RBP = \pi_{(1,s)} + \sum_{j=0}^{s} \pi_{(0,j)} + \sum_{j=0}^{s} \pi_{(2,j)} \tag{4}$$

III. SIMULATION

To validate the Markov Chain model presented in the previous section, we have written a simulator which simulates a VAN scenario as follows. In the VAN, request for new calls arrive at the rate of about one call per minute ($\lambda = 0.016$) following a Poisson process. If a call is accepted, it remains in the network for an average of 2 minutes ($\mu^{-1} = 120$) with the actual length of the call following an exponential distribution. To simulate a reasonable load on the satellite (or cellular) link that connects the VAN to the Internet, we assume $S = 4$ (this yields a RBP of about 10% when $\Delta = 0$). The tunnels are simulated by having the VAN-to-Internet connectivity breaking down periodically, where actual durations of both connectivity (outside tunnel) and non-connectivity (inside tunnel) are drawn from exponential distribution. The mean values of the exponential distributions are selected to ensure that on average the fraction of time the VAN spends in a tunnel (no connectivity to the Internet) does not exceed 0.1 or 10% of the total time of the trip ($\beta^{-1} = 1000$, $\alpha^{-1} = 111.11$).

All new call requests are rejected when the VAN is inside a tunnel, or Δ seconds away from entering a tunnel. A call request that arrives when the VAN is neither in a tunnel, nor within Δ second from entering a tunnel, is accepted only if there are less than four calls currently being supported by the network, rejected otherwise. Whenever the VAN enters a tunnel, any ongoing call is marked as disrupted. A call is marked disrupted only once irrespective of how many tunnels (disruptions) it has to face. As the simulation progresses, totals of new, accepted, rejected, and disrupted calls are computed. >From these totals, the RBP is computed as the fraction of total new call requests that are rejected. SDP is obtained as the fraction of total accepted calls that were disrupted.

$$\pi_{(i,j)} = \begin{cases} (\frac{1}{\frac{1}{\Delta}})(\beta\pi_{(i-1,j)} + \mu\pi_{(i,j+1)}) & i = 2,\ j = 0 \\ (\frac{1}{\frac{1}{\Delta}+j\mu})(\beta\pi_{(i-1,j)} + (j+1)\mu\pi_{(i,j+1)}) & i = 2,\ 1 \leq j \leq (s-1) \\ (\frac{1}{\frac{1}{\Delta}+j\mu})\beta\pi_{(i-1,j)} & i = 2,\ j = s \\ (\frac{\frac{1}{\Delta}}{\alpha})\pi_{(i+2,j)} & i = 0,\ 0 \leq j \leq s \\ (\frac{1}{\beta+\lambda})(\alpha\pi_{(i-1,j)} + \mu\pi_{(i,j+1)}) & i = 1,\ j = 0 \\ (\frac{1}{\beta+j\mu})(\alpha\pi_{(i-1,j)} + \lambda\pi_{(i,j-1)}) & i = 1,\ j = s \\ (\frac{1}{\beta+j\mu+\lambda})(\alpha\pi_{(i-1,j)} + \lambda\pi_{(i,j-1)} + (j+1)\mu\pi_{(i,j+1)}) & i = 1,\ 1 \leq j \leq (s-1) \end{cases} \quad (1)$$

We have run a total of 14 simulations, each with a different value for Δ selected between 0 and 250 seconds. Each simulation was run long enough so that the RBP and SDP values converge to steady state and yield a 95% confidence level with less than 5% relative precision. Simulation results are presented along with the corresponding analtyical results in the following section.

IV. Results

The SDP and RBP values, obtained from the Markov Chain as well as the simulation, as a function of Δ are shown in Figures 3 and 4. In these figures, $\Delta = 0$ means no calls are rejected before entering the tunnel if there is spare bandwidth in the satellite (or cellular) link (i.e., traditional admission control). As expected, any increase in Δ directly reduces SDP, because the admission controller now admits only those calls which arrive farther from the tunnel entrance. The RBP experiences the opposite effect, because more call requests, which arrive closer to the tunnel, are now rejected. The more interesting and important result is that the SDP decreases *quadratically* while RBP experiences a *linear* increase (a close match between simulation and analytical results confirms the validity of our Markov Chain model).

The quadratic reduction of SDP at the expense of linear increase in RBP is definitely encouraging. However, it should be noted that even with a linear increase, the net increase in RBP can be substantial. For example, by setting Δ to 120 seconds (the mean call duration), GAC reduces SDP from 0.033 to 0.016 at the expense of increasing the RBP from 0.1 to 0.21, which could be significant. The exact trade off to aim for would depend on how the operators, or more importantly the users, weigh these two important quality of service parameters (RBP and SDP). For example, if rejection is preferred over disruption, Δ should be set to a high value. On the contrary, if users are happy with some occasional disruptions, but are really annoyed if a request is blocked, then Δ should be zet to (close to) zero. The key contribution to highlight here is that GAC empowers the VAN operators to trade off RBP for SDP, and the proposed Markov Chain model accurately captures this trade off.

V. Related Work

The concept of using geographic location to influence admission control decisions has been studied before in the context of low earth orbit satellite networks [4]. The algorithm

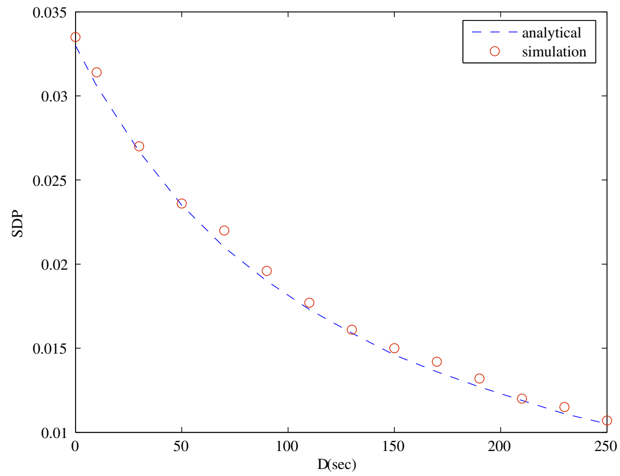

Fig. 3. SDP as a function of Δ ($\lambda = 0.016$, $\mu^{-1} = 120$, $\beta^{-1} = 1000$, $\alpha^{-1} = 111$, S = 4)

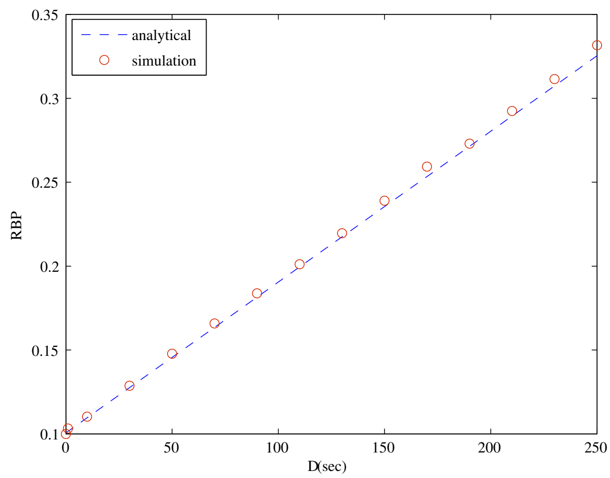

Fig. 4. RBP as a function of Δ ($\lambda = 0.016$, $\mu^{-1} = 120$, $\beta^{-1} = 1000$, $\alpha^{-1} = 111$, S = 4)

utilizes the deterministic movement of the satellites and the knowledge of user locations to estimate the blocking probability of a new call and accepts the call only if the estimated blocking probability does not exceed a target threshold. This context is totally different from the VANs, where we have to model service disruption probability as well as the call blocking probability.

Reducing service disruptions to multimedia calls in disconnecting VANs has been considered before by other researchers [5]–[7]. However, the focus of all these works is to *prefetch* the contents from the Internet to a local proxy-server ahead of the disconnection, and play out the contents from the proxy during the disconnected period. While prefetching is indeed considered an effective method to reduce service disruptions in disconnecting environments, it requires additional mechanisms to be deployed both in the VAN and in the Internet servers. In our current work, we do not consider any prefetching. Rather, our focus is in the modeling of the effectiveness of geographic admission control. Our work can be extended to include prefetching, which would be an interesting future direction to pursue.

For a given traffic load (for Poisson arrivals and exponentially distributed service times), the well known Erlang B formula [8] yields the probability that all the system resources (e.g., channels or bandwidth) would be occupied, which is often referred to as the *blocking probability* of the system. While the original Erlang formula remains a popular choice for dimensioning a wide range of networks and systems, its use remains limited to networks that has deterministic properties of its resources (i.e., no disconnections or no variation in the resource state). Recently, researchers [9] have demonstrated that, in the face of varying link quality, dimensioning mobile networks using traditional Erlang B loss model leads to inaccurate prediction. While the author of [9] proposed a more generalized version of the original Erlang B to address the quality variation in the radio link, no such generalization has been reported (to the best of our knowledge) to address network disconnectivity.

VI. Conclusion

In VANs, ongoing services may get disrupted when the vehicle passes through challenging radio zones, e.g., deep tunnels. Since the knowledge of such 'radio unfriendly zones' can be made readily available to all vehicles, it is possible to reduce disruption probability simply by not admitting new calls when a VAN is about to enter a tunnel. We have explored the benefit of using such geographic knowledge in the CAC function of the VAN by constructing a Markov Chain model of the problem. As expected intuitively, any reduction in SDP is achieved at the expense of an increased RBP. The interesting finding, however, is that the SDP reduces quadratically, while the RBP exhibits a linear increase. This finding may motivate VAN operators to adopt GAC, especially if the impact of SDP and RBP on user satisfaction could be established. Because the accuracy of the model has been verified by simulation, the model can be used by the VAN operators to dimension their networks.

VII. Future Work

The current work revealed some interesting results that could potentially be achieved using geographic admission control in VANs. However, there exists several unexplored aspects of geographic admission control which could be pursued further as future work. For example, in our current work, we have assumed that vehicles can accurately estimate time to tunnel using their current location and the location of the tunnel. In practice, however, there are many extraneous events, e.g., road traffic, that may impact the actual arrival time to the tunnel. How to improve time-to-tunnel estimation using vehicle-to-vehicle or vehicle-to-infrastructure communication would be an interesting future direction.

Performance evaluation of GAC in the presence of time-to-tunnel estimation errors would be an important future work as well. In particular, this work would directly explore the validity of the proposed Markov Chain model under noisy estimations of vehicular travel times.

Another ineteresting direction would be to establish how SDP and RBP, individually and as a combination, impact user satisfaction. For example, given two combinations, (RBP=0.2, SDP=0.05) and (RBP=0.3, SDP=0.02), which one makes the users more satisfied? This work is important because at the end of the day, the VAN operators would want their customers to be satisfied.

Finally, it would be interesting to test the concept of GAC using real tunnel (and other network) data. The relationship between SDP and RBP, as dictated by the practical data, would provide more valuable insight into the selection of the Δ parameter.

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