Cabernet- Vehicular Content Delivery using Wi-Fi

N. Sasikiran[1] M. Sudhakar Reddy[2] K.Venkat[3]
[1, 2, 3]Student
[1, 2, 3] Scsvmv University, Kanchipuram

Abstract---Cabernet is a system for delivering data to and from moving vehicles using open 802.11 (Wi-Fi) access points encountered opportunistically during travel. Using open Wi-Fi access from the road can be challenging. Network connectivity in Cabernet is both fleeting (access points are typically within range for a few seconds) and intermittent (because the access points do not provide continuous coverage), and suffers from high packet loss rates over the wireless channel. On the positive side, Wi-Fi data transfers, when available, can occur at broadband speeds. In this paper, we introduce two new components for improving open Wi-Fi data delivery to moving vehicles: The first, Quick Wi-Fi, is a streamlined client-side process to establish end-to-end connectivity, reducing mean connection time to less than 400 ms, from over 10 seconds when using standard wireless networking software. The second part, CTP, is a transport protocol that distinguishes congestion on the wired portion of the path from losses over the wireless link, resulting in a 2× throughput improvement over TCP. To characterize the amount of open Wi-Fi capacity available to vehicular users, we deployed Cabernet on a fleet of 10 taxis in the Boston area. The long-term average transfer rate achieved was approximately 38 Mbytes/hour per car (86 Kbit/s), making Cabernet a viable system for a number of non-interactive applications.

Keywords: Vehicular networks, vehicle-to infrastructure, open Wi-Fi access

I. INTRODUCTION

This paper describes the design, implementation, and experimental evaluation of Cabernet, a content delivery network for vehicles moving in and around cities. Cabernet delivers data to and from cars using open 802.11b/g (Wi-Fi) access points (APs) that the cars connect too opportunistically while they travel. Cabernet is well-suited for applications that deliver messages (e.g., traffic updates, parking information, event and store information, email) and files (e.g., maps, software updates, documents, web objects, songs, movie clips, etc.) to users in cars, as well as for applications that deliver messages and data from devices and sensors on cars to Internet hosts [16, 22].

These applications do not require interactive end-to-end connectivity between a sender and receiver.

When a car connects via a Wi-Fi AP, it can potentially transfer data at the same rates as static clients connected to the same network. However, as cars move, their

Connectivity is both *fleeting*, usually lasting only a few seconds at urban speeds, and *intermittent*, with gaps from dozens of seconds up to several minutes before the next time they obtain connectivity. In addition, we observe that packet loss rates over the wireless channel are both high (often 20%) and vary over the duration of a single AP association. The primary goal of Cabernet is to develop techniques that allow moving cars to obtain high data transfer throughput, despite these adverse conditions.

Stock implementations of wireless networking protocols are not well suited to vehicular applications for three reasons. First, current client implementations take too long—several seconds—to scan and associate with an AP, acquire an IP address, and establish end-to-end connectivity in the face of the high packet loss rates in this environment. Second, current end-to-end data transfer and congestion control protocols do not work well when connectivity is only a few seconds long and intermittent, and wireless loss rates are high (as is the case for moving cars). Third, default wireless bit-rate selection algorithms are tuned to non-moving users, resulting in suboptimal performance in vehicular applications.

Cabernet incorporates three techniques to mitigate these problems:

To reduce the time between when the wireless channel to an AP is usable and when Internet connectivity through the AP is actually achieved, we have developed Quick Wi-Fi, a streamlined process that combines all the different protocols involved in obtaining connectivity (across all layers) into a single process, including a new optimal channel scanning policy.

To improve end-to-end throughput over lossy wireless links, we have developed the Cabernet Transport Protocol (CTP), which outperforms TCP over opportunistic Wi-Fi networks by not confusing Wi-Fi losses for network congestion. Unlike most previous work on efficient wireless transport protocols, CTP does not require modifications to APs (which are not under our control); instead, it uses a lightweight probing scheme to determine the loss rate from Internet hosts to an AP.

To improve link rates, we study the impact of bit-rate selection in vehicular Wi-Fi. Based on our results, we adopt a static 11 Mbit/s Wi-Fi bit-rate for transfers from the car. This optimization could not be applied for downloads from Internet hosts, as the AP controls the bit-rate in this direction.

The Cabernet design and protocols presented in this paper have been fully implemented. The system is currently deployed in 10 taxis running in the Boston area. The results reported in this paper are from the real-world operation of this test bed, with the in-car nodes running Quick Wi-Fi and the system running CTP. Our key experimental findings are as follows:

Many short connections Quick Wi-Fi enables the use of many brief connection opportunities, resulting in a relatively short mean connection time of 10 seconds (median 4 seconds) com-pared to previous work. Correspondingly, the mean time between successful encounters is also lower.

Fast connection establishment Quick Wi-Fi reduces the time to associate with a wireless network from a

previously reported average of 12-13 seconds [8, 15] to 366 ms. we find that 70% of connection opportunities last less than 10 seconds. Given the large number of brief connection opportunities, Quick Wi-Fi provides a four-fold increase in the number of connections that transfer data during drives, compared to a system without Quick Wi-Fi. By not reacting to non-congestion losses over the wireless link, CTP improves data delivery rate by a factor of two over TCP. Experiments over 2300 connections showed minor differences in loss rates between 1 Mbit/s and 11 Mbit/s rates, and a dramatic increase in losses when using 802.11g (OFDM) rates. End-to-end performance attained (Section 8): Each car in our test bed was able to download 38 MByte per hour (86 Kbit/s) while moving, averaged over periods with and without connectivity. Re-sponse times can be high, due to intermittent, burst connectivity. For example, the observed mean time from request to receiving a 1 MByte response was 9 minutes. These results suggest that Cabernet is well suited to a large class of non-interactive applications.

Of course, there are non-technical issues surrounding both the large-scale use and deployment of open access points. We address these issues briefly in Section 10.

II. Related Work

Now a days, delivery of information to moving cars is done mainly using wide-area cellular data networks such as GPRS, 3G, EVDO, etc. In general, these services cost tens of dollars per month. We envision Cabernet as an alternative for "lower end" and embedded mobile information services, which do not justify the cost of a cellular data plan subscription. For example, in our test bed the price of an EVDO cellular data plan is approximately $720/year per car, making it prohibitively expensive for many users and services. It is likely, however, that many users will eventually have cellular data service available on their cell phones. Such connectivity could conceivably be shared with embedded devices in the car, given that these could be properly authenticated. Compared to such solutions, Cabernet makes no assumptions about drivers' other data services, and requires no prior configuration.

With the proliferation of municipal and public Wi-Fi initiatives, in addition to major commercial initiatives, Cabernet is likely to be sufficient for many applications. Even if the cost were not an issue, the *fundamental* capacity of Cabernet is much higher than current cellular networks: given enough access points, the high link speed and intense spatial reuse of Wi-Fi is unlikely to be matched by any cellular system. Because Cabernet does not provide continuous connectivity, however, our goal is to complement cellular data services, not to replace them.

In Vehicular networks, the Drive-Through Internet, and Infostations projects propose architectures similar to Cabernet. The main difference is that Cabernet uses existing, unmodified APs, and has been evaluated extensively under real-world conditions on a taxi-based test bed. Several projects have studied the problem of intermittently connecting from cars or other mobile devices to the Internet. Our previous work in the Cartel project investigated general architectures for vehicular sensor networks, and characterized the extent to which wireless access points deployed in cities can be used as an uplink network for moving cars [8]. This work did not address network performance issues, such as optimized association, scanning, data transport protocols or rate selection.

The UMass Diesel Net is a delay-tolerant network running on 40 buses in Amherst. They have studied protocols for bus-to-bus routing in delay tolerant networks as well as measurements and models of bus-to-bus connectivity. In a set of techniques are proposed to enable web search from a bus, using only Wi-Fi connectivity. The authors report an average meeting duration of 55-58 seconds, significantly higher than the 10 seconds we report. This result is a side-effect of using QuickWifi: due to the long connection establishment delays incurred using standard techniques, Diesel Net was likely unable to take advantage of connections shorter than 10-15 seconds (>70% of connections in our experiments). They report a median time of 5-8 minutes between successful connections vs. 32 seconds for Cabernet. However, due to the difference in mobility (bus vs. car), and setting (Amherst vs. Boston), these numbers are not directly comparable.

A detailed study of Wi-Fi connectiv-ity from a vehicle by repeatedly driving past a single access point in an isolated area without other interference or obstructions.). In Cabernet however, the mean connection only lasts about 19 seconds, and many connections never achieve "good" connectivity; we find packet loss rates in excess of 10% throughout many connections. They suggest tuning timeouts in the wireless stack to improve performance, but do not experimentally evaluate the effects of such changes. We have implemented a number of optimizations in QuickWifi, including various timeout optimizations. Finally, unlike in our experiments, they find that bit rates above 11 Mbit/sec are usable and TCP losses are low. We attribute the significant differences between our respective findings to the fact that their experiments were conducted in a relatively controlled and benign setting.

Study signal quality between two vehicles and several base stations. They find that harsh fading occurs throughout the duration of a vehicular Wi-Fi connection, and that such periods of poor connectivity can be predicted based on past history. Our results corroborate these, and an interesting direction for future work would be to incorporate their AP prediction algorithms into Cabernet.

Delay tolerant networks. A variety of work on delay tolerant networks [10, 18, 19, 26, 29, 5, and 21] has studied architectures, routing, forwarding, and analysis of intermittent and high-delay networks. In contrast, our focus is not on routing—we assume that mobile nodes are just a single hop from well-connected, fixed infrastructure—but on maximizing the utility of that single-hop path.

III. Experimental Setting

Before describing the components of the system in more detail, we briefly summarize the characteristics of our experimental test bed, the equipment used, and the data gathered. It consists of 25 nodes, each a Soekris 4801 computer, equipped with a Ubiquity.

The results reported in this paper were derived from a variety of experiments with varying duration and overlap. In total, we have successfully transferred data using 26000 open APs. This is out of several hundred thousand observed APs all together, the vast majority of

which were encrypted. However, except where noted otherwise, most results were computed using 124 hours of actual mobility, defined as driving periods with a maximum stop of 2 minutes. Note that we had no control over vehicle mobility—these measurements were truly gathered "in the wild". That said, it is likely that some of the results reported here may look different when compared to results from private cars or public transport, both of which may have less diverse travel patterns.

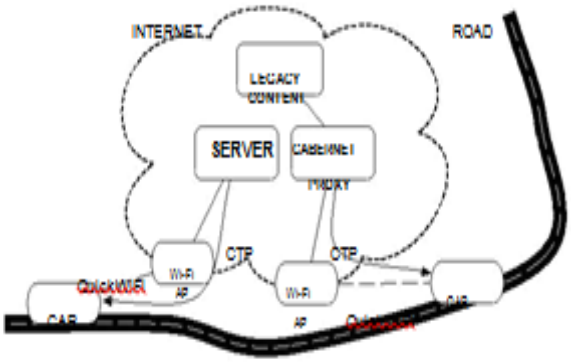

Fig. 1: Cabernet architecture. Cabernet-equipped cars briefly connect through open Wi-Fi access points as they move

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IV. Design Overview and Goals

This section describes the architecture of Cabernet, illustrated in Figure 1. As a car drives down the road, the onboard embedded computer repeatedly scans for, and attempts to associate with, open APs. It then attempts to establish end-to-end connectivity with a Cabernet enabled host, to retrieve or upload data. Software running on the embedded computer uses QuickWiFi to connect as quickly as possible, and CTP to deliver data (instead of TCP, though TCP could also be used). Finally, communication with legacy Internet hosts is done using a proxy that serves two functions: first, it hides intermittent connectivity from protocols running on fixed Internet hosts and shields them from changing IP addresses, and second, it translates between CTP and popular protocols like HTTP and TCP.

At a high level, Cabernet's design can be described by the follow-ing three objectives:

1. Establish connectivity quickly to take advantage of brief con-nection opportunities.
2. Split congestion control between wired and wireless portions of the path to cope with high non-congestive wireless loss rates.
3. Expose the appearance and disappearance of connectivity to Cabernet-enabled applications on the mobile node.

We motivate and discuss each of these in turn below.

V. QuickWiFi Operation

QuickWiFi incorporates fully automatic scanning, AP selection, as-association, DHCP negotiation, address resolution, and verification of end-to-end connectivity, as well as detection of the loss of con-nectivity. It is implemented as a single state machine, running in one process. The result is a tight integration between steps: each step is executed immediately after the previous step has completed, and parallelism is exploited whenever possible. We now describe some of the optimizations incorporated in QuickWiFi.

In the current implementation, QuickWiFi attempts to associate with the first open access point it encounters as it scans through the wireless channels. After a connection is complete, it resumes scanning at the point where it left off. In practice, this policy results in a quick way to select a random AP, since any AP beacon may be the first one heard when a scan begins. As future work, it would be interesting to explore schemes that cache historical AP connectivity information so that APs with better connectivity are selected with higher probability. Such schemes are tricky to implement as they require waiting for a scan to complete (decreasing usable connection times) and can also decrease the chances that new APs are discovered and used.

Tuned for vehicular Wi-Fi. Authentication, association, DHCP, and ARP all include timeout/retry protocols. Retries are very likely; particularly in DHCP discovery and ARP request phases when broad-cast messages (without link-layer ACKs) are used. By reducing timeouts to hundreds of milliseconds (which is far longer than the typical wireless channel round trip time), rather than seconds (as in most stock implementations), we can dramatically reduce the mean connection establishment time. In QuickWiFi, the timeout period in each phase is set to 100 ms, after which the request is sent again, up to 5 times. If the 5th request fails as well, the process starts over with the scanning phase. The choice of 100 ms here is somewhat arbitrary. Further improvements may be possible by tuning the timeout interval depending on the message type.

Back-to-back authentication/association. Even open APs re-quire clients to authenticate, but this step is always successful. Thus, there is no need to wait for the response to our authentication request before sending the association request. Should the authentication request be lost in the meantime, the subsequent association request will fail, and QuickWiFi will automatically restart the process.

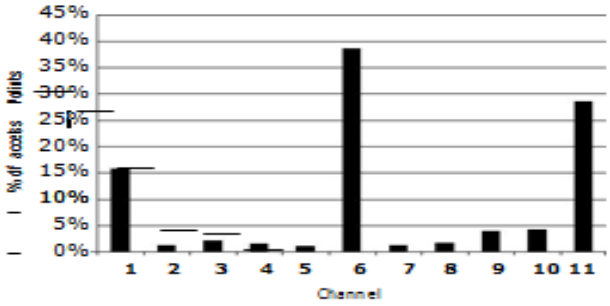


Fig. 2: Distribution of APs across channels.

A. *Vehicular Wi-Fi Rate Selectio*

In IEEE 802.11 networks, the sender may choose a bit rate from amongst a list of rates supported by both sender and receiver. Hence, when downloading data to cars in Cabernet, the AP controls the rate. Unfortunately, the bit-rate adaptation protocols used by most APs are optimized for stationary users, and even the best current rate adaptation schemes require multiple seconds to settle on the optimal rate, which makes them unsuitable for Cabernet.

Since we cannot control the rate selection scheme used for down-loads, we ran a series of experiments to measure the effect of bit-rate selection on uploads. We believe that these results would apply to download as well if APs had support for vehicular clients. Specifically, our experiments measure the loss rate of uploads from moving vehicles transmitting at different bit rates. 802.11b supports 4 wireless transmission rates, 1, 2, 5.5 and 11 Mbit/s, and 802.11g (OFDM) adds several more rates, ranging from 6 through 54 Mbit/s.

During an encounter, we periodically sent bursts of 10 1000-byte frames to the AP, and recorded whether an acknowledgment was received, and after how many retries. Each frame was sent at a rate chosen uniformly at random from the supported rates advertised by the access point. The experiment was run on 10 vehicles, over the course of 2338 encounters with 531 unique access points. After initial experimentation showed that they performed significantly worse than the 11 Mbit/s rate, we did not include the 802.11g rates 6, 9 and 12 Mbit/s. time required to send a large packet at 1 Mbit/s is almost 10x the time required at 11 Mbit/s, negating any reliability benefit that could be had by switching to the lower rate. Moreover, looking at the conditional success probability given a previous failure (the light grey bar), we see that even after losing packets, reducing the rate would not result in a performance gain.

In summary, current rate adaptation schemes are highly useful for stationary users, where signal quality varies slowly. However, in the case of Cabernet, the combination of rapid mobility and marginal channel quality means that a suitable adaptation scheme must adapt very quickly to realize a performance gain. Because the 11 Mbit/s rate overall performed so much better than the other rates, Cabernet currently uses only that rate. Based on these findings, we implemented a "fixed 11 Mbit/s" rate selection strategy on our taxi test bed. We use this modified rate selection protocol throughout the experiments reported in this paper. The full benefits of this optimization cannot be seen, however, because most of our experiments focus on download performance from the Internet to cars, where the (unmodified) APs control the bit rate.

B. *End-to-End Performance*

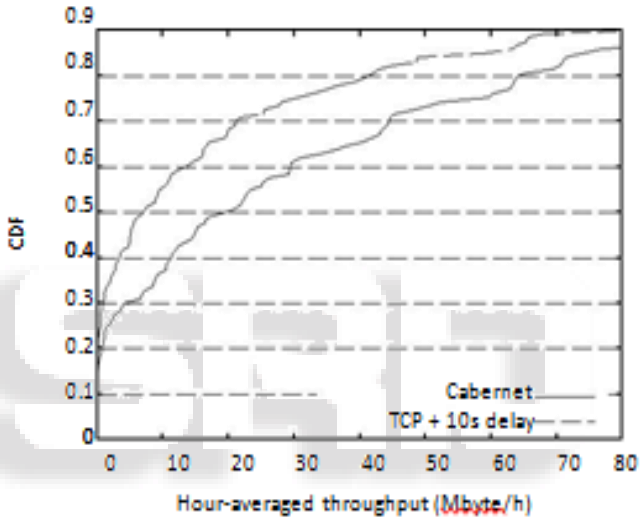
Having established the performance of QuickWiFi and CTP in isolation, we now turn to the overall performance of the implemented system. The experiments described below seek to answer the follow-ing key questions and explain observed performance:

1. What is the expected time between a request for information, and the retrieval of the desired response?
2. Given Wi-Fi conditions in the Boston area, what is the expected time-averaged throughput of a Cabernet-equipped vehicle?

C. *Expected Transaction Time*

For applications that react to external stimuli, such as passing a landmark, a timer expiring, or a user action, the expected time taken to complete a network transaction is of interest. We envision a usage scenario where an application requests a download of a given size, at an arbitrary time. We then compute the time it would take Cabernet to complete the download.

Figure 15 shows the expected response time t_r , for a varying transaction size s. The median response time for a small (10 Kbyte) request was 2 minutes, and the mean was 5 minutes. Typical requests of this nature may include traffic and weather updates, requesting driving directions, polling RSS feeds, and checking for new email. For larger transfers, such as downloading a full web page, large emails with attachments, or a 1 minute audio clip, we consider a 1 Mbyte request. The median time for such requests was 4 minutes, and the mean time was 9 minutes.



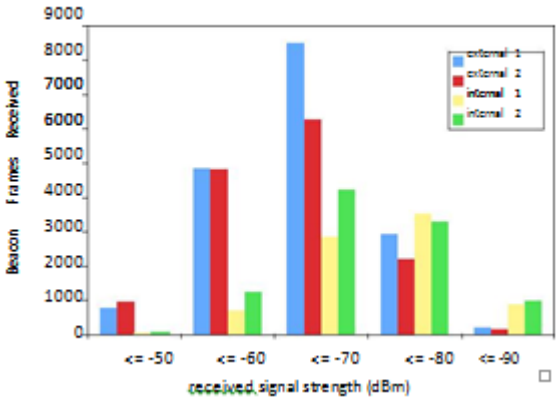
Hour-averaged throughput (Mbyte/h)

Fig. 3: CDF of the expected number of bytes downloaded, per hour of driving, per car, with and without Cabernet.

D. *Expected long-term Throughput*

For less time-sensitive applications, such as podcasts, prefetching of web pages, or background file synchronization, the metric of interest is total download capacity, rather than transaction time. As we demonstrate below, Cabernet provides ample throughput for such applications.

We divide the driving time of each car into hour-long segments, and compute the total download throughout each time segment. Fig-ure 16 shows the CDF of the available hour-averaged throughput when using Cabernet. For comparison, we also show TCP through-put after reducing (via post-processing) the total download time of each encounter by an *estimated* connection establishment delay of 10 seconds, to account for the improvement in connection establish-ment time due to QuickWiFi. In conclusion, we find that the mean throughput for Cabernet in the Boston area was 38 Mbyte/hour (86 Kbit/s).



Received signal strength (dBm)

Fig. 4: Received signal strength vs. antenna choice. Often difficult to install, an external high-gain antenna can dramatically improve reception.

VI. Conclusion

This paper described Cabernet, a system for delivering data to moving vehicles. Cabernet uses Wi-Fi access points encountered during drives for network connectivity. This intermittent connectivity presents several challenges, including high connection establishment latency and high Wi-Fi loss rates.

To improve throughput, we developed CTP, a transport protocol that handles high non-congestive wireless loss rates by running a lightweight probing protocol between a sender and the access point to isolate congestion events on the Internet path from last-hop losses. CTP is able to achieve double the throughput of TCP over paths with high non-congestion losses, with a mean throughput of 800 Kbit/s when connectivity is present. Finally, in an end-to-end performance evaluation, we find that Cabernet is able to achieve an end-to-end throughput of 38 megabytes/hour (86 Kbit/s) per car during its drives—ample throughput for a large class of non-interactive vehicular applications.

References

[1] U. Lee, B. Zhou, M. Gerla, E. Magistretti, P. Bellavista, and A. Corradi. Mobeyes: smart mobs for urban monitoring with a vehicular sensor network. IEEE Wireless Communications, 13(5), Oct. 2006.

[2] R. Mahajan, J. Zahorjan, and B. Zill. Understanding Wi-Fi-based connectivity from moving vehicles. In IMC, 2007.

[3] S. Mascolo, C. Casetti, M. Gerla, M. Y. Sanadidi, and R. Wang. TCP Westwood: Bandwidth Estimation for Enhanced Transport over Wireless Links. In Proc. ACM Mobicom, July 2001.

[4] J. Ott and D. Kutscher. A Disconnection-Tolerant Transport for Drive-thru Internet Environments. In INFOCOM, 2005.

[5] A. Seth, P. Darragh, S. Liang, Y. Lin, and S. Keshav. Architecture for Tetherless Communication. In DTN Workshop, 2005.

[6] T. Small and Z. J. Haas. The shared wireless infostation model: A new ad hoc networking paradigm (or where there is a whale, there is a way). In MOBIHOC, pages 233–244, 2003.

[7] X. Zhang, J. Kurose, B. N. Levine, D. Towsley, and H. Zhang. Study of a Bus-Based Disruption Tolerant Network: Mobility Modeling and Impact on Routing. In Proc. ACM Mobicom, pages 195–206, September 2007. W. Zhao, M. H. Ammar, and E. W. Zegura. A message ferrying approach for data delivery in sparse mobile ad hoc networks. In MobiHoc, pages 187–198, 2004.

[8] S. Jain, K. Fall, and R. Patra. Routing in a Delay Tolerant Network. In ACM SIGCOMM, 2004.

[9] P. Juang, H. Oki, Y. Wang, M. Martonosi, L. Peh, and D. Rubenstein. Energy-efficient computing for wildlife tracking: Design tradeoffs and early experiences with zebranet. In Proc. Architectural Support for Programming Languages and Operating Systems, October 2002.

[10] U. Kubach and K. Rothermel. Exploiting location information for infostation-based hoarding. In MOBICOM, pages 15–27, 2001.J. Lebrun, C.-N. Chuah, D. Ghosal, and M. Zhang. Knowledge-based opportunistic forwarding in vehicular wireless ad hoc networks. In IEEE Vehicular Tech. Conf., pages 2289–2293, 2005

