Extensive GPRS Latency Characterization in Uplink Packet Transmission from Moving Vehicles

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***Abstract*—The GPRS (General Packet Radio Service) broad availability is driving a widespread development of mobile telemetry systems for fleet management, supply chain management and dangerous goods monitoring applications.**

In this paper we present the results of extensive measurements of the GPRS network-layer uplink latency performed over a four-month period from about fifty road trucks using telemetry service, providing an uplink latency characterization in a moving vehicle environment. The results show the relationship between vehicle speed and latency.

Furthermore, the performances of the stop-and-wait in a moving vehicle environment are evaluated in order to design a variant of such a protocol based on a vehicle speed-aware retransmission timeout.

I. Introduction

GPRS (General Packet Radio Service) is a wireless wide-area network packet switched service that supports IP (Internet Protocol) connectivity. The broad availability of this service at relatively low costs is increasingly pushing the development of mobile telemetry systems, targeted to application domains such as fleet management, supply chain management, dangerous goods monitoring, etc.

In mobile telemetry systems, vehicular terminals generate periodic telemetry messages, encapsulate them in single UDP/IP packets and send them to a central server through the GPRS network. Telemetry messages are typically characterized by

- a generation interval of some tens of seconds (e.g., from 20 to 60 seconds)
- a small data payload (e.g., 50-100 bytes) to carry values such as GPS geographic coordinates, on-board sensor samples, etc.
- low message delivery latency requirements (a few seconds) to support real-time applications, such as alarm notifications
- low retransmission overhead requirements to reduce communication costs overheads.

Considering such characteristics, the most widely adopted transport-layer transmission policy for telemetry is a stop-and-wait service, based on timeout-triggered retransmission of unacknowledged packets, with no transmission window. Even in this basic transmission policy, the latency jitter characterization represents a crucial aspect in order to adjust the protocol retransmission timeout to maintain a low retransmission overhead and a low message delivery latency.

Considering that in literature the GPRS latency jitter is widely characterized in static environments but only roughly in moving environments, the main contribution of this paper is to report the statistics of network-layer uplink latency in a extensive experimental setup, showing that the speed of the vehicle that hosts the mobile system impacts on the transmission latency over the GPRS network. The statistics are significant as they take advantage of data gathered over a four-month period from about fifty road vehicles using continuative telemetry service. These results suggest designing speed-aware roundtrip estimation systems.

A. Related Work

Several works analyze the performance of connectivity in a live GPRS network. Most of them can be classified in two categories:

- *Passive analysis*, based on the collection of large amount of traffic traces on the link between the GPRS network and the Internet ([1], [2]). This methodology does not allow knowing whether the traffic comes from moving nodes or from stationary nodes.
- *Active analysis*, based on the generation of sample traffic between a limited number of MSs (Mobile Station) and a reference server. This methodology allows characterizing the performance of moving nodes vs. stationary nodes and it is the one adopted in our study. Previous works ([3], [4], [5]) do not analyze the impact of the vehicle speed on the packet latency, but they characterize stationary vs. moving transmission nodes in a qualitative way.

As a consequence, to the best of our knowledge, there are no quantitative analyses performed on a significant number of measurements aimed at characterizing the effect of vehicle speed on IP packet delivery latencies over GPRS network.

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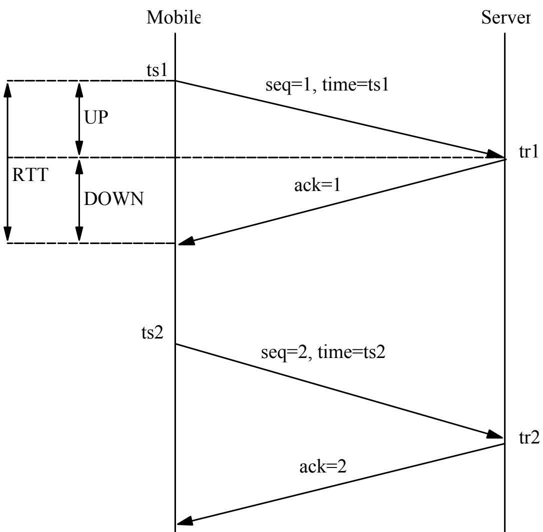

Fig. 1. Diagram of the stop-and-wait protocol adopted in the test system.

B. Roadmap

The paper is organized as follows. Section II describes the experimental setup including the operational conditions. Section III shows the results extracted from the data collected during the experiments. Section IV provides an analytical analysis of the behaviour of the stop-and-wait protocol adopted in the test system and the performance evaluation of a variant of the stop-and-wait that takes advantage of a vehicle speed-aware timeout. Section V provides some concluding remarks.

II. Experimental Setup

We performed an extensive analysis on the server log traces of a commercial remote telemetry system for road trucks. Such a system consists of a number of remote terminals, installed on trucks, and a central server connected to an Internet Service Provider having a direct peering link to the GPRS telecom operator. The terminals are equipped with a Siemens MC39i GPRS module (GPRS class 10, 1 uplink slot, 4 downlink slots) and a GPS receiver. Measurements are based on 49 mobile terminals during a 110-day period between June and September 2007, corresponding to 123,035 packets from the terminals. Only data packets containing a valid GPS position have been considered, as the GPS position fix provides the vehicle speed value (see section II-A) and the clock synchronization (see section II-B).

A. Data exchange protocol

The data exchange protocol between the server and the remote terminals is based on the transmission of UDP (User Datagram Protocol) packets, following the stop-and-wait policy. Data communication is initiated by the remote terminal that sends a UDP datagram to the server; when the server receives the datagram, it sends back an acknowledgment datagram to the terminal (see Fig. 1). If the acknowledgment is not received before timeout expiration (because of a packet loss or a too long roundtrip time) the terminal retransmits the packet.

The UDP payload of the telemetry message is about 100 bytes long, sent every 60 seconds, and includes a message sequence number, a timestamp, the GPS geographic coordinates and speed, and some on-board sensors' data. The acknowledge datagram has a payload of 6 bytes. Table I shows the speed distribution of the packets received during the test period.

TABLE I
Speed Distribution

Speed Range (km/h)	Number of messages
0	78,874 (64.1 %)
(0,30]	10,906 (8.9 %)
(30,60]	12,038 (9.8 %)
(60,90]	21,217 (17.2 %)
Total	123,035 (100.0%)

B. Latency measurements

The measured uplink latency (tagged "*UP*" in Fig. 1), corresponds to the time interval between the packet transmission time (*ts*) on the MS and the packet arrival time (*tr*) on the server.

$$UP = tr - ts\,. \tag{1}$$

As every telemetry packet contains a generation time timestamp having the granularity of 1 second, and the arrival time is reported on the log traces with the same precision, *UP* is measured with a 2-second precision. Note that the MS real-time clock is synchronized with the GPS time, while the server clock is synchronized with a pool of time servers using NTP (Network Time Protocol), with about 0.1-second precision.

C. Geographic area

The road trucks monitored by the test system are based in North Italy. Fig. 2 shows a graphic representation of the samples' location.

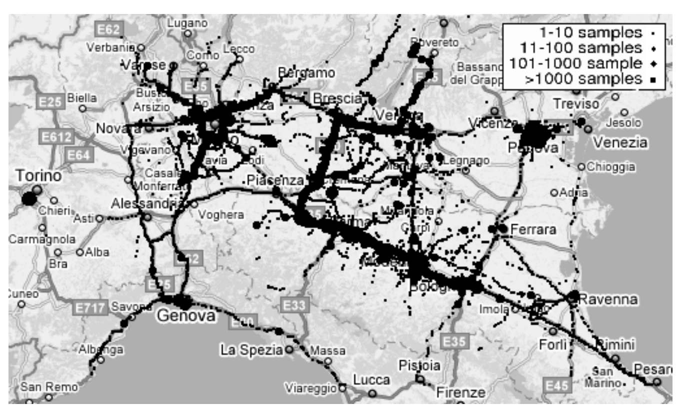

Fig. 2. Geographic location of the samples collected during the test period.

III. UPLINK LATENCY ANALYSIS

GPRS networks exhibit significant delay jitter that can be triggered by the following causes, widely studied in literature:

a) Variable radio conditions cause different rates of link level retransmissions.
b) The GPRS infrastructure performs buffering at several layers of the protocol stack (see [4]). However small packet size and low packet generation rate of telemetry application are unlikely to cause buffering.
c) The cell reselection process can cause delay spikes in uplink. The main impact of cell reselection can be observed in moving MSs: in [4] the authors show that cell reselection in moving MSs can suspend data transfer from 3 to 15 seconds.
d) Isolated packets (or first packet in a sequence), which are very frequent in telemetry applications, can be affected by the time needed by the TBF (Temporary Block Flow) establishment procedures. In [6] the authors show that the TBF establishment procedures can take up to 500 ms.

A. *Field Test results*

The measurements collected in our experiment allow extracting a discrete probability distribution with a 2-second granularity due to the measurement precision. Fig. 3 shows the histogram of the uplink latency (*UP*) against vehicle speed, Fig. 4 shows a detail of the same histogram, Table II reports the histogram values.

Data samples have been classified in four speed categories, i.e., zero speed and three contiguous 30km/h-wide ranges. The histogram shows the relationship between the uplink transmission latency and the vehicle speed. When the vehicle is not moving (white bars), 97.2 percent of the packets are characterized by an uplink latency below 2 second. On the second category such percentage falls to 93.8%, on the third to 91.9% and on the fourth to 90.5%, about 7% less than the stationary case. The distribution tail shows that higher vehicle speeds correspond to higher probability of long latencies.

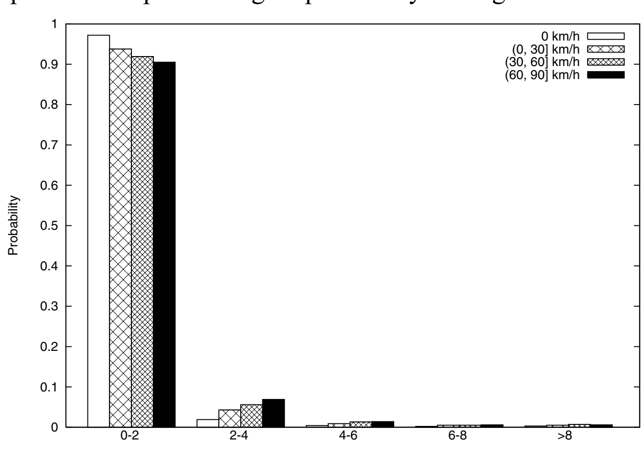

Fig. 3. Histogram of the uplink latency during the test period.

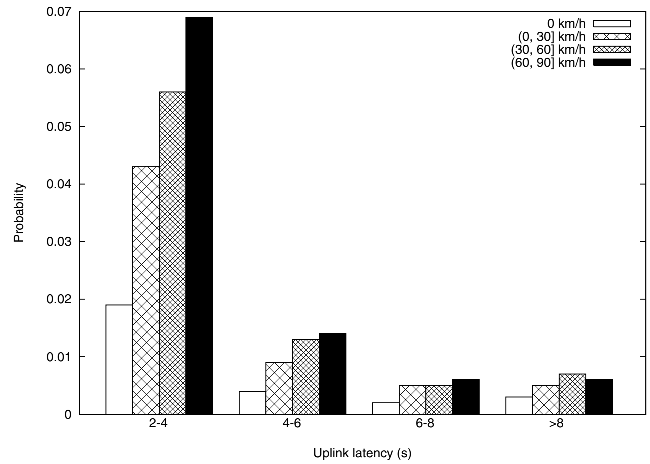

Fig. 4. Histogram (UP > 2 s) of the uplink latency during the test period.

TABLE II
PROBABILITY MASS FUNCTION OF THE UPLINK LATENCY

Latency range (s)	Probability			
	0 km/h	(0,30] km/h	(30,60] km/h	(60,90] km/h
0-2	0.972	0.938	0.919	0.905
2-4	0.019	0.043	0.056	0.069
4-6	0.004	0.009	0.013	0.014
6-8	0.002	0.005	0.005	0.006
>8	0.003	0.005	0.007	0.006

IV. STOP-AND-WAIT PROTOCOL PERFORMANCE EVALUATION

The analysis presented in this section takes advantage of the distribution presented in Section III *i*) to quantitatively evaluate the performance of the stop-and-wait protocol adopted on the test system, and *ii)* to devise a variant of stop-and-wait that improves the transmission performance based on a vehicle speed-aware retransmission timeout.

Two performance metrics are considered:

a) *Late arrival rate* (γ): defined as the fraction of messages that arrives to the server later than a given time k (γ = Pr[$\tau > k$]), where τ is the *message delivery time*, defined as the time interval between the message generation time and the arrival of the message to the server. In case of arrival of multiple copies, due to retransmission(s), the arrival time corresponds to the time of the first arrived copy. As a consequence, when packet losses occur, τ depends on the protocol timeout, i.e., large timeout values cause large message delivery times. The late arrival rate can be significant in several applications, e.g., when transmitting urgent alarms.
b) *Retransmission overhead* (λ): defined as the number of packet retransmissions performed by the sender due to retransmission timeout expiration over the total number of sent messages. Also λ depends on the protocol timeout, as shorter timeout values increase the probability of

timeout expirations before the arrival of the acknowledgments, even in case of no losses.

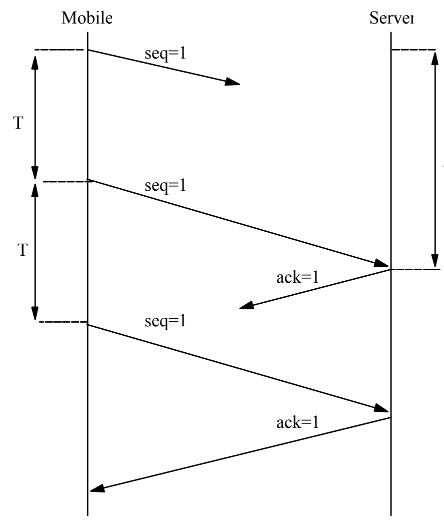

Fig. 5. Packet sequence diagram in case of an uplink loss during the first transmission followed by a downlink loss on the second transmission. In this case, there are two retransmissions and the message delivery time (τ) is the sum of the first timeout period (T) plus the uplink time of the second transmission.

The analysis is based on the following assumptions:

a) Constant loss rate (L) in uplink and in downlink. In our analysis L = 0.01 (i.e., 1% of losses in uplink, 1% in downlink).
b) The uplink latency (UP) is a random variable. In our analysis the probability distribution of UP is the one presented in Table II. The instances of UP are independent one from another.
c) The roundtrip time (RTT), due to the lack of experimental results, is approximated as $RTT=2\cdot UP$.
d) The retransmission timeout of the stop-and-wait protocol is denoted by T.

Table III shows the results obtained for the retransmission overhead (λ) in the test system for various timeout in the 4-16 second range. We report the details of the expressions in the Appendix. The graph in Fig. 6 represents the values of the table.

For example, let the application specifications require a 5% retransmission overhead and a maximum of 1% of late arrival messages (k = 6 s). In the non moving case, a 5% retransmission overhead can be obtained using a 4-second timeout. However, maintaining that timeout value, at higher vehicle speed the overhead reaches 12.75%; in order to obtain a 5% overhead over the entire speed range, an 8-second timeout is needed. Higher timeouts increase the delivery time in case of packet losses during the transmission, causing an increase of the late arrival rate (γ).

TABLE III
RETRANSMISSION OVERHEAD

Timeout (s)	λ			
	0 km/h	(0,30] km/h	(30,60] km/h	(60,90] km/h
4	4.98%	8.79%	11.03%	12.75%
8	2.97%	4.02%	4.66%	4.76%
12	2.55%	3.07%	3.28%	3.28%
16	2.35%	2.55%	2.76%	2.66%

L = 0.01

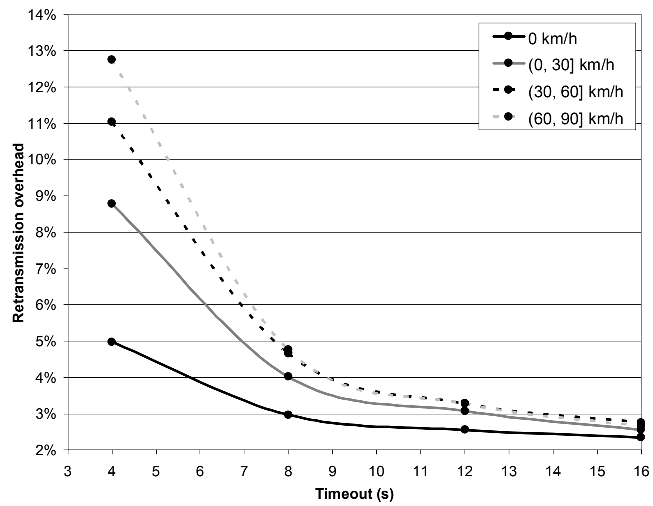

Fig. 6. Retransmission overhead λ. (L = 0.01)

A speed-aware variable timeout scheme can be employed to minimize the late arrival rate while maintaining a given overhead value. In our example, using a 4-second timeout when the vehicle is not moving and an 8-second timeout otherwise, it is possible to maintain a 5% overhead over the entire speed range. Table IV shows the retransmission overhead (λ) and the delayed messages (γ, k = 6 s) using three different timeout schemes:

- Constant timeout of 4 seconds.
- Constant timeout of 8 seconds.
- Variable timeout scheme (4 seconds when the speed is zero, 8 seconds when the speed is greater than zero).

The values on the table are obtained using the metrics values at different speeds weighted by the actual speed distribution showed in Table I.

It can be noted that the specifications of our example can be met only by the variable timeout scheme.

TABLE IV
PERFORMANCE METRICS USING DIFFERENT TIMEOUT SCHEMES

Timeout (s)	γ	λ
Constant (T=4)	0.73%	7.25%
Constant (T=8)	1.73%	3.54%
Variable	1.09%	4.82%

L = 0.01; k = 6 s

V. CONCLUDING REMARKS

In this paper we have presented the results of extensive measurements performed on a vehicular remote telemetry system based on GPRS. In particular, we provided a detailed characterization of the network layer uplink latency jitter at various vehicle speeds.

Using such measurements, we simulated the effects of the vehicle speed on a stop-and-wait transport-level protocol, showing that a vehicle speed-aware variable timeout scheme can be used to maintain a low retransmission overhead while maintaining an upper bound on the telemetry information delivery time.

Future work involves a more precise characterization of the network layer latency performances of GPRS in a vehicular environment, including a less than 2 second precision and an evaluation of the downlink component of the latency. Furthermore, an accurate quantification of packet losses in such an environment has not been done yet.

APPENDIX

In this section we present the analytical results used to obtain the retransmission overhead (λ) showed in Table III and Fig. 6, and the late arrival rate (γ) showed in table IV. This methods are based on the results presented in [7], section 2.1, adapted to our test case.

- Let T be the protocol retransmission timeout.
- Let UP be the random variable representing the packet uplink latency.
- Let RTT be a random variable representing the RTT of a message, with probability distribution function $B(x) = \Pr[RTT \le x]$.
- Let L be the loss rate, both on the uplink and on the downlink.

A. Late arrival rate

The probability that a message is lost in the uplink *n-1* times and received correctly the *n*-th time is

$$L^{n-1}(1-L). \quad (2)$$

The probability that the message delivery time (τ) is less or equal than a constant *k* can be written as

$$\begin{aligned}\Pr[\tau \le k] &= \Pr[UP \le k](1-L) + \Pr[T + UP \le k]L(1-L) + \\ &\Pr[2T + UP \le k]L^2(1-L) + \ldots\end{aligned} \quad (3)$$

Thus:

$$\gamma = \Pr[\tau > k] = 1 - \Pr[\tau \le k] \quad (4)$$

B. Retransmission overhead

Let D be the probability that the ACK is not received before timeout is reached, and that the current packet is retransmitted. Then

$$D = 1 - B(T)(1-2L). \quad (5)$$

The probability that the message is retransmitted n times before that the ACK is received in time (before timeout expiration) is

$$D^{n-1}(1-D). \quad (6)$$

Then, the mean number of packet retransmissions (zero in case of no retransmission) performed by the sender to receive an ACK for that packet before timeout expiration can be written as

$$\lambda = \sum_{n=1}^{\infty}(n-1)D^{n-1}(1-D) = \frac{D}{1-D} = \frac{1}{B(T) - 2LB(T)} - 1. \quad (7)$$

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