REAL TIME MAPPING WITH DGPS-ENABLED NAVIGATION EQUIPMENT

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ABSTRACT:

Today, differential GPS techniques allow common GPS receivers to achieve the precision levels required for mapping purposes. The development of systems for mobile Internet access (mainly GPRS) provides a fast and reliable method for feeding differential corrections to a GPS receiver in any area covered by a cell telephone network. With the increase in the available bandwidth, and the example of data streaming applications like Internet-Radio or Internet-TV, the researchers are now trying to use the Internet as a medium for transmitting GNSS code and phase corrections for real-time surveys, and examining advantages and limitations of this approach. In this context the EUREF (*EUropean REference Frame*) started in June 2002 a project named EUREF-IP, with the purpose of developing a stable and robust infrastructure for broadcasting differential corrections via Internet. Inside this project the Topography Section of the University of Cagliari has settled up a permanent station, which since July 2002 sends differential corrections over the Internet for DGPS and RTK positioning. The permanent station, identified as "CAGZ", is part of the IGLOS network and, since October 2003, of the EPN network. This paper describes the CAGZ permanent station, the servers software and the field tests performed during this two years of uninterrupted GNSS data transmission, to evaluate the performances of the two servers activated. Also different network connections (LAN, GSM-Internet, GPRS-Internet) were compared in order to assess the improvements achieved by transmission medium. We present also some DGPS ant RTK surveys, performed with geodetic and hand-held receivers for updating medium-scale and large-scale cartography.

1. INTRODUCTION

With the growing possibilities of the Internet and the increase in the available bandwidth, applications like Internet-Radio or Internet-TV data streaming are becoming mature and stable. This brought the researchers to use the Internet as a medium for transmitting GNSS code and phase corrections for real-time surveys. Research in this field has put in evidence advantages and limitations of this approach.

Among the many advantages, one is overcoming the single-user limitation, typical of transmission systems like the GSM modem. Corrections broadcast via Internet are in fact available from an assigned Web address and port, therefore several users can connect with any wireless system (GSM, GPRS, UMTS) and through any Internet provider to that address and download in real time the differential corrections. Another advantage over radio transmissions is not being bound to a limited range from the reference station, as long as the client has a connection to the Internet.

On the other hand, this method has some drawbacks such as high network latency times and sudden disconnections from the server during the survey. Latency is surely one of the greatest problems, especially in RTK surveys, and is substantially tied to the data transmission rate, and thus the system used for connecting to the Internet. Currently we have a range of 9.6 kbit/s (with a GSM modem) to 57.6 kbit/s (with a GPRS connection), up to a potential rate of 2 Mbit/s for the UMTS network (not yet completely operative in Italy). Also, the data rate can be influenced by network overload conditions. The scientific community tries to find solutions to these problem, in order to improve the reliability of the transmission of corrections from the server to the clients. In this context the EUREF (*EUropean REference Frame*) started in June 2002 a project named EUREF-IP, with the purpose of developing a stable and robust infrastructure for broadcasting differential corrections via Internet.

Inside this project the Topography Section of the University of Cagliari has settled up a permanent station, which since July 2002 sends differential corrections over the Internet for DGPS and RTK positioning. The permanent station, identified as "CAGZ", is part of the IGLOS network and, since October 2003, of the EPN network.

The transmission of the differential corrections is performed by two server applications; one developed at the project start by the Cagliari research group named DGGI (*Differential GPS and GLONASS via Internet*); the other, active since June 2003, uses the NTRIP infrastructure (*Networked Transmission of RTCM over IP*) developed by the EUREF. The advantages of NTRIP over the simple TCP connection used (among others) by DGGI are described by its authors in (Weber, 2003)

This paper describes the CAGZ permanent station, the servers software and the field tests performed during this two years of uninterrupted GNSS data transmission, to evaluate the performances of the two servers activated. Also different network connections (LAN, GSM-Internet, GPRS-Internet) were compared in order to assess the improvements achieved by transmission medium.

2. THE CAGLIARI PERMANENT STATION

2.1 The Permanent Station

The first step in joining the EUREF-IP project was building a server to broadcast the permanent station corrections. The station consists of a GPS+GLONASS Javad-Topcon Legacy/E receiver with external frequency source (cesium) and a Regant-2 choke-ring antenna. The receiver firmware is able to generate the RTCM messages for code-differential and RTK corrections.

The Internet server runs on a PC with an AMD Duron 700MHz CPU, 128 MB RAM, 30 GB HD, and Linux SuSE operating system. The PC is connected to the receiver (via serial cable) and to the Internet.

The RTCM messages are sent over the Internet by two servers, one written in the Python language, and the other supplied by the EUREF-IP within the NTRIP project.

Figure 1. The GPS+GLONASS Permanent Station CAGZ

2.2 The DGGI Server

The Python language was chosen for its features of portability between different OSs and rapid application development.

Given the peculiar characteristics of the server, we did not use the standard server classes of the Python library (much more oriented towards FTP- or HTTP-like servers).

The DGPS server main program (base_dgps_stream.py) uses two class libraries ("modules", in Python terms). The first one (gril.py) defines the classes used to communicate with the Javad GPS receiver, using its proprietary GPS Receiver Interface Language (GRIL). The other (TCP_Broadcaster.py) defines the TCP_Broadcaster class, which is the actual TCP server. The main program thus creates the two objects, "receiver" and "server", connects them, and initializes the RTCM messages transmission.

The figure 2 shows the UML sequence diagram of the server. Basically, the server waits for connection requests on the TCP 2101 port (assigned by IANA for the DGPS transmissions over the Internet). Every client which sends a connection request is added to a list of active clients. At the same time, the program checks if new data are available on the receiver by using the select() system call. If this is the case, it downloads the new data and sends them to all the connected clients. If while sending data to a client a TCP error (ECONNRESET or ENOTCONN) is encountered, this means that the client is no longer listening; thus, the connection is closed and the client is removed from the list.

The DGPS corrections (RTCM 1 and 31 messages) are sent every 3 seconds while the station information (messages 3 and 16 with the station name and coordinates) are sent every 30 seconds. At the present time, the station also sends the RTCM 18 and 19 messages for RTK.

The service has a web page with all the information about the permanent station and the transmitted RTCM messages. The service, which is online since July 2002, is free of charge. The DGGI server software code is available upon request (the receiver setup and communication modules are specific to the Javad-Topcon receiver).

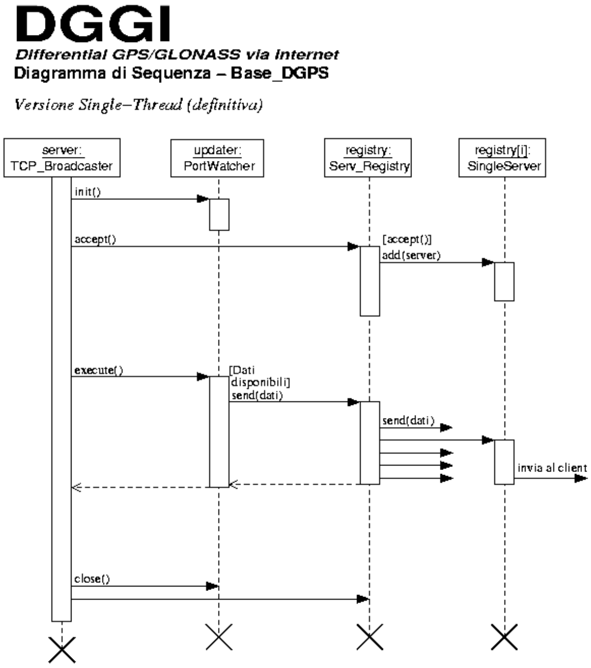

Figure 2. Scheme of the DGGI Server

2.3 The NTRIP Server

The NTRIP Server, supplied by the EUREF-IP project, uses a protocol based on HTTP/1.1, adapted to support the streaming of GNSS data. The system is implemented in three applications, named *NtripServer*, *NtripClient* and *NtripCaster*. The former two are technically HTTP clients, while the latter is the true HTTP server. The *NtripServer* software runs on the permanent station PC, and as a client connects to the *NtripCaster* on the port 80 (assigned to the HTTP protocol), then sends to it the differential corrections as the receiver produces them.

The *NtripCaster* is a HTTP server based on *Icecast*, a free (GNU license) software designed to broadcast streaming media (mainly audio and video) on the Internet. Such an architecture was chosen for its ability to send its data to many users (even thousands) at the same time. The *NtripCaster*, redesigned to manage GNSS data, keeps updated a “source table” listing all the active data sources (permanent stations) which can supply RTCM corrections.

The *NtripClient*, or “GNSS Internet Radio”, runs on the client computer (be it a common PC , a lap-top, or a hand-held system with Windows CE), which is connected to the “rover” GPS receiver by a serial cable. Upon starting, the software downloads the source table; the user selects the station whose RTCM correction will be used (usually the nearest one); then, the software connects to the chosen station and starts downloading the corrections, which are sent to the receiver through the serial port.

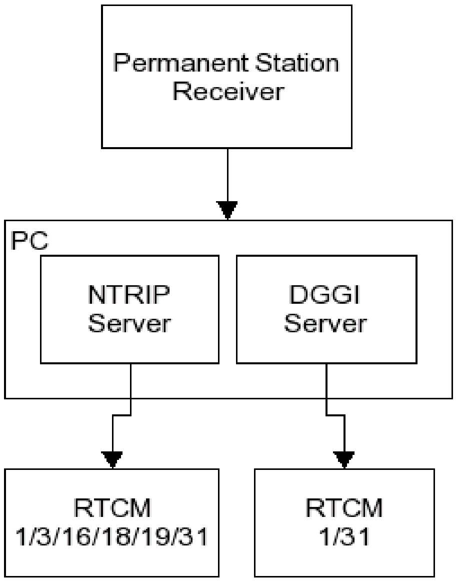

Figure 3. Scheme of The Permanent Station with the RTCM Servers

3. THE CLIENT/ROVER

3.1 Client Architecture

The client is based on a GPS receiver, which can be of geodetic class (if a sub-decimeter precision is required) or hand-held (if 1-meter precision is enough). In the former case the RTK or DGPS mode will be used, in the latter the DGPS mode only.

3.2 Client for the RTK Tests

The first solution is based on a Javad-Topcon GPS+GLONASS L1L2 geodetic receiver with a LegAnt antenna. The receiver can apply code and phase differential corrections, having a RTK/OTF positioning engine with centimetric precision. The receiver is connected to a notebook PC, in turn connected to the Internet by a GSM-GPRS modem. The built-in RTK engine can operate in “delayed” or “extrapolated” mode. In “delayed” mode, the observations are processed regardless of the correction latency time, by using an internal buffer storing up to 6 observations preceding the current one (based on the rover time), waiting to receive from the “base” a correction with the same time tag. This positioning mode (which could be defined “near-real-time”) produces spatially precise positions, like the ones obtained from post-processing, but temporally delayed by a time equal to the latency of the corresponding corrections. If the latency is over 6 seconds, a single-point solution is produced. The current rover position can be improved by adding a trajectory model which allows to bring the position up to date. As the latency time increases, so decreases the precision of the coordinates. There is no precision loss for static-type positioning, thus this mode is better suited for topographic applications, such as “stop-and-go” surveys, where the operator can stop on a point until the receiver fixes the position with a adequate precision.
The “extrapolated” mode is useful for navigation and real-time precision positioning, rather than topographic applications. In this mode the RTK engine tries to extend the validity of the previous corrections, by using the range rate correction and extrapolating the correction (or observation) up to the current time tag. The advantage of this mode is having an up-to-date position (the determined position at every time is the current one according to the receiver time), but less precise spatially. The positioning precision depends on the decorrelation in time of the observations, so to a greater latency corresponds a lesser precision. Beyond a certain latency (usually 15 seconds), the RTK engine is no longer able to fix the ambiguities, which remain in “float” state. In this mode, the NMEA output from the receiver reports the latency of each correction, giving a way to evaluate the quality of the coordinates. In “extrapolated” mode, better results are reached if the receiver can use the RTCM 20 and 21 messages, rather than 18 and 19, due to the better temporal stability of the phase range corrections when compared with the raw data.

3.3 Client for the DGPS Tests

The DGPS tests were carried out with GPS+GLONASS receiver Legacy/E Topcon (the same model used at the permanent station) with a LegAnt 2 antenna; we also used an iPAQ hand-held PC with GPRS mobile phone for the Internet connection, and a Compaq Presario notebook PC with the ArcView-ArcTracking software to display real-time path.
Tests on DGPS were also performed using a Trimble GeoExplorer hand-held GPS receiver with an integrated Windows CE computer. The receiver works in DGPS mode and the corrections can come from an external station in RTCM format, or directly from the WAAS system. Internet-based corrections are downloaded by an iPaq hand-held PC with GSM-GPRS modem card, and sent to the GeoExplorer through a serial cable connection. The ESRI ArcPad GPS software runs directly on the GeoExplorer.

4. FIELD TESTS

4.1 RTK Tests

RTK tests with the receiver in static postion were planned both in “delayed” and “extrapolated” modes, at various distances from the master station; the former with the purpose of testing the infrastructure quality, the latter in order to measure the latency of the corrections. Distances from the permanent station were fixed at (about) 10 m, 3 km, 6 km, and 15 km. In order to avoid differences in satellite configurations, all tests were scheduled at almost the same time every day. The transmission media used for all tests was the Internet (via GSM and GPRS mobile connections); for the 10 m test we also used a direct Ethernet connection (within the same LAN as the server station) for comparison. The systems for broadcasting the corrections over the network were the *NtripServer* with the RTCM 3/18/19 messages, and the DGGI server with two RTCM message sets: 3/18/19 and 3/20/21. Table 1 collects all tests planned for this experimentation, not all of which were actually performed. The experiments used a receiver-specific routine to compare the three components of the actual base-rover baseline (obtained from a 1-hour static survey) with those computed in RTK mode during the tests. If the difference on each component falls under 6 cm, the position is considered correct. Each test comprised a set of at least 30 fixings, where the RTK engine was reinitialized after each fixing.

Client/Server	Ntrip	DGGI	Modem
Lan - Ethernet	18/19	18/19, 20/21	
GPRS - Internet	18/19	18/19, 20/21	
GSM - Internet	18/19	18/19, 20/21	
Modem			18/19, 20/21

Table 1. Planned Tests

4.1.1 Delayed mode test: The robustness of the infrastructure and the improvement brought by the Ntrip protocol where evaluated by using three figures of merit (FOM) (adapted from Cannon, 2003) for the phase ambiguity fixing. The first one (I_1) consists of the percentage of ambiguities fixed within a given number of epochs. The second (I_2) is the percentage of correctly fixed positions. Finally, the third FOM (I_3) is the time required to fix a given number of ambiguities (30); this accounts for the many single-point positions due to the excessive latency of the corrections. Tables from 2 to 7 show the results of the tests on the distances of 10 m, 3 km, and 15 km.

The FOMs for the 10 m test allowed us to compare the GSM and GPRS connections with the Ethernet LAN, whose latency time was not influenced by network traffic (being the network so small). The results put in evidence the good response of GPRS in respect to GMS, and of both GPRS and GSM in respect to the LAN. The DGGI server did not show differences with the *Ntrip* either using the 18/19 messages, or the 20/21 ones.

The tests performed at distances of 3 and 5 km have shown that *Ntrip* has a more stable behaviour compared with DGGI, due to the automatic reconnection system typical of the streaming protocols. In fact as the distance increases, only using *Ntrip* the time required to fix a given number of ambiguities (I_3) remains almost constant. Also the GPRS network response is nowadays equal if not better than the GSM one.

Corrections Transmission Mode		Ntrip	DGGI	
			Msg 3/18/19	Msg 3/20/21
I_1		100	100	100
I_2	< 5 s	88	100	97
	< 7 s			
	< 15 s	90		100
	> 15 s	100		
I_3		209	160	150

Table 2. LAN Connection (10 m)

Corrections Transmission Mode		Ntrip	DGGI	
			Msg 3/18/19	Msg 3/20/21
I_1		100	100	100
I_2	< 5 s	52	100	91
	< 7 s	95		96
	< 15 s			100
	> 15 s	100		
I_3		272	453	196

Table 3. GPRS Connection (10 m)

Corrections Transmission Mode		Ntrip	DGGI	
			Msg 3/18/19	Msg 3/20/21
I_1		100	100	100
I_2	< 5 s	52	0	0
	< 7 s	92	91	91
	< 15 s	95	98	98
	> 15 s	100	100	100
I_3		240	480	240

Table 4. GSM Connection (10 m)

Corrections Transmission Mode		Ntrip	DGGI	
			Msg 3/18/19	Msg 3/20/21
I_1		100		100
I_2	< 5 s	0		45
	< 7 s	94		55
	< 15 s			70
	> 15 s	100		100
I_3		240		over 600 s

Table 5. GPRS Connection (3 km)

Corrections Transmission Mode		Ntrip	DGGI	
			Msg 3/18/19	Msg 3/20/21
I_1		100		100
I_2	< 5 s	78		81
	< 7 s	89		86
	< 15 s	91		89
	> 15 s	100		100
I_3		480		over 600 s

Table 6. GSM Connection (3 km)

Corrections Transmission Mode		Ntrip	DGGI	
			Msg 3/18/19	Msg 3/20/21
I_1		68		61
I_2	< 5 s	0		39
	< 7 s	59		
	< 15 s	83		91
	> 15 s	100		100
I_3		300		over 600 s

Table 7. GPRS Connection (15 km)

4.1.2 Extrapolated mode test: As already said, in "extrapolated" mode latency times are directly reported in the NMEA GGA messages. This way, it is possible to plot a diagram of the latency values relative to the fixed positions. Figure 4 shows a comparison of the results for the LAN, GSM and GPRS connections, on the distance of 10 m.

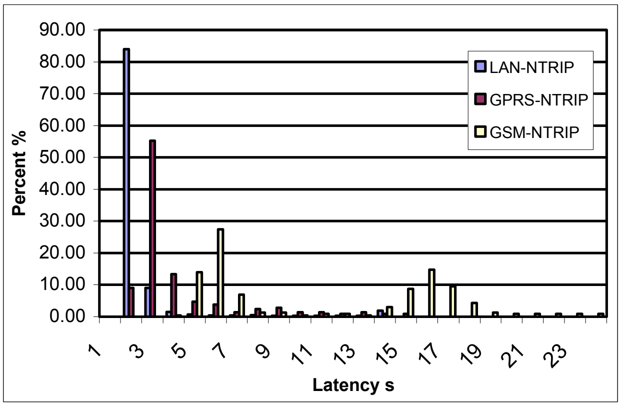

Figure 4. Comparison of the latency times

The diagram shows that the latency is lower in the LAN connection (1-2 s), higher in the GPRS (3-4 s), an even higher in the GSM (over 7 s).

In order to evaluate the improvements brought by the *Ntrip*-GPRS systems, the results of the RTK "extrapolated" session, carried out on September 2003, were compared with those of a

similar session performed in August 2002 using the DGGI server, when the EUREF-IP system was just starting.
Comparing the values (Figure 5) puts in evidence the remarkable improvement brought by the *Ntrip* system and by the more stable GPRS network.

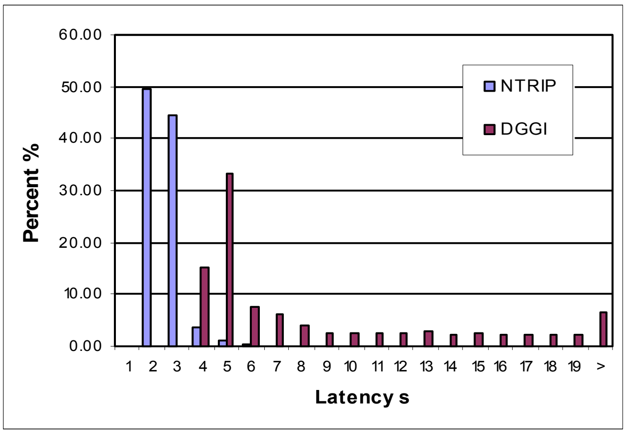

Figure 5. NTRIP-DGGI server comparison

4.2 DGPS Tests

The initial DGPS mode test was performed using the Javad-Topcon geodetic GPS+GLONASS receiver in the Cagliari city area, scheduled in order to have the maximum GLONASS visibility. The receiver, besides sending the NMEA messages to the connected PC, recorded the raw data on its internal memory for later post-processing, in order to have a comparison with the real-time results. The raw data recorded in the survey were processed in kinematic mode with those of the permanent station CAGZ. For every epoch, we calculated the distance between the point obtained from DGPS and the one from kinematic post-processing (KIN-PP), and the distance between stand-alone position (PPS) and KIN-PP (Figure 6). The differences in height were calculated by the same way. The r.m.s. were 0.89 and 1.27 m for DGPS, 5.5 m and 22.5 m for SPP, respectively in horizontal and in height.

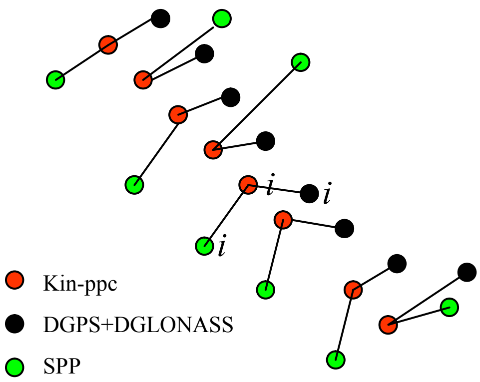

Figure 6. Comparison between obtained positions

Figure 7 shows a GPS survey performed in order to update a 1:10000 cartography in the Cagliari area.
Other DGPS tests were performed with a Trimble GeoExplorer hand-held GPS receiver.
The tests were performed in small urban areas in Cagliari. DGPS mode tests have been performed both in motion and in fixed positions; the instrument was carried by an operator which followed on foot the path to be surveyed. The first surveys regarded elements already present in the 1:1000 maps, in order to evaluate the precision of the system. Later, new elements were surveyed and inserted in the map. The results confirmed the expected precision for the real-time differential mode, which was sub-meter.

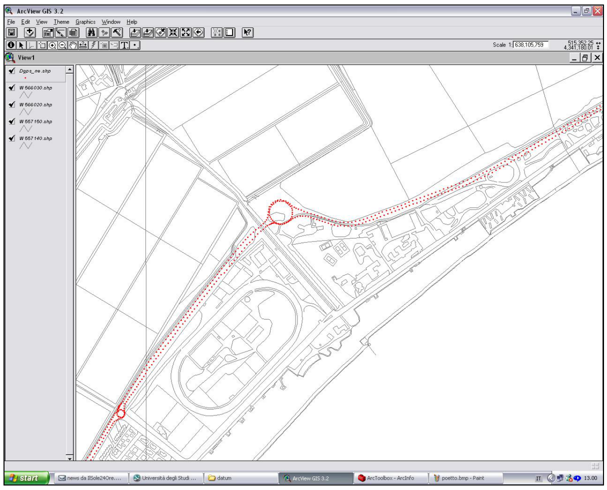

Figure 7. DGPS survey using geodetic receiver

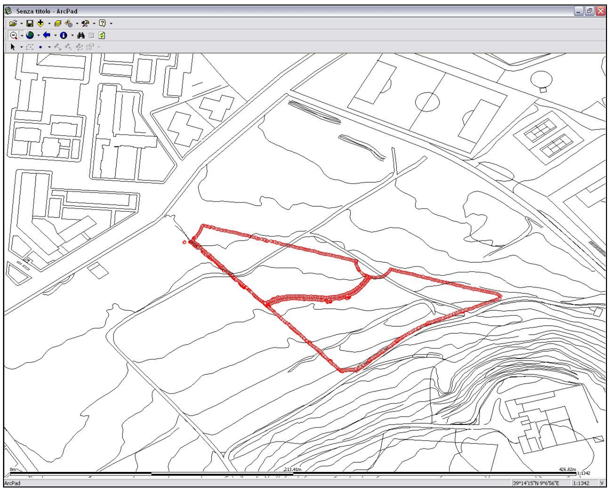

Figure 8. DGPS survey using hand-held receiver

5. CONCLUDING REMARKS

The tests have shown that the positioning precision level obtained using the Internet as a transmission medium for differential GPS code and phase corrections depends upon different factors, such as the protocol used or the connection system. It was evident that using a simple TCP-connection protocol is not sufficient to ensure the necessary robustness to the system, while using multicast-oriented systems like Icecast the stability is substantially improved.
In this work we preferred the GPRS over the GSM as a connection system, because of the competitive costs offered by the telephone companies in Italy. In fact, the GPS connection are priced on the volume of transmitted and downloaded data (which is very low in the case of DGPS data), while the GSM costs are time-based. Anyway, the latency times with the GPRS connection have been found to be lower than the GSM ones,

due to the more advanced infrastructure.

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