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USING OF GSM-GPRS NETWORK AND INTERNET FOR DIFFERENTIAL GPS (GNSS)

The expansion of Internet connectivity by GSM-GPRS network to transport elements allows new possibilities of differential GPS (GNSS) techniques and applications. This paper presents several ideas of effective DGPS protocol design intended for UDP packet layer of GSM-GPRS communication channel.

UŻYTKOWANIE SIECI GSM-GPRS ORAZ INTERNETU W RÓŻNICOWYM SYSTEMIE GPS

Rozwój komunikacji GSM-GPRS pozwala na powstanie nowych możliwości zastosowań technik GPS. Zakłada się, że łączenie z Internetem poprzez GSM-GPRS lub inne sieci radiowe będzie standardem dla elementów wyposażenia transportu. Wydatki na taki system zależą głównie od całkowitych pojemności kanału danych – przekazywanych lub otrzymywanych. Aktualnie na świecie nie jest określony standard zalecanego pasma oraz protokołu danych dla kanału GPRS. Dlatego w referacie przygotowano odpowiedni protokół przesyłu danych. Osiągalny w praktyce współczynnik kompresji jest 10-15 większy w porównaniu do binarnego formatu danych, a 5-50 jedno-sekundowe obserwacje mogą być zapisane w jeden pakiet.

1. INTRODUCTION

The GPS is well known as a global navigation satellite system. The analogous systems are the Russian GLONASS and GALILEO system prepared by EU. Actually, the GPS is the only one fully applicable global satellite position determination system on the world.

The reachable GPS performance for most of civil users (Standard position service - SPS) is limited; therefore, it is not sufficient for some applications. In these years, the performance limits are caused by native measurement errors (ephemeris error, satellite clock error, ionospheric and tropospheric refraction, multipath effect and receiver imperfection). The system precision for SPS users can be significantly reduced by technique known as Selective Availability (SA). The SA is suspended at present, but it is liable to political and military decision. Besides, the system integrity is insufficient for many of life safety applications.

The considerable improvements in accuracy and integrity are accessible by differential measurement methods (DGPS, DGNSS). These improvements arise because the largest measurement errors are strongly correlated over distance and vary slowly with time. The

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differential system accuracy is limited by residual errors only, i.e. mainly by residual atmospheric signal refraction and multipath effect.

The differential techniques are based on processing of measurement records from twice of GPS receivers – user receiver and reference receiver. Consequently, a data communication channel is a necessary part of each real-time differential application. At present the General Packed Radio Service (GPRS) of GSM network appears as a perspective link with relative sufficient technical and economical parameters. The non-existence of appropriate DGPS data standard for the GSM-GPRS channel appears as other barrier for immediate usage. The requirement analysis and draft of suitable protocol is a topic of this work.

2. ANALYSIS OF REQUIREMENTS

Since 2^{nd} May 2000, the SA was turned off. Due to this, position accuracy for GPS SPS users increases to 8-25 m (95%, horizontal). In implication of this, the DGPS users structure changed. The autonomous GPS accuracy became sufficient for many of applications with mean accuracy requirements (e. g. navigation on road in urban areas). At present, DGPS techniques are used in applications with high accuracy or integrity requirements.

DGPS protocols without carrier phase information (e.g. RTCM SC104, message 1 or 9) are suitable for standard position accuracy only (1-5 m). The absence of carrier phase information causes a limitation of multipath effect suppresses. For accurate applications, the carrier phase information is necessary. Besides, it is desirable to prepare extensions for new expected signal components (GPS L2-C/A, L5).

The zero level of SA causes a change of time characteristics of GPS measurement errors. The time correlation and dynamics of these errors depend considerable on actual state of ionosphere. The mean period of DGPS data retransmission may be extended significantly, but it has to be adaptive according to immediate requirements (depend on momentary state of ionosphere, etc.). The DGPS correction may be extrapolated on the receiver side in continuance of data retransmission interval. The extrapolation error will be monitored in the reference station, because this station knows correction values, what were sent to this user. As soon as extrapolation error overflows given limit, the new correction set may be sent immediately.

Operating expenses of GSM-GPRS communication depend on total received or transmitted data capacity. Therefore, the DGPS data protocol needs ensure the minimal cumulative data volume that is the minimal average data bandwidth.

A special message or other protocol instrument has to be prepared for well-timed integrity warnings.

3. ANALYSIS OF CURRENT DGPS DATA STANDARDS

The DGPS systems can be classified according to form of data transmitted through a communication channel between the reference station and the user equipment. The first group of DGPS systems uses corrections, which are computed in reference station as a difference between measured and expected pseudoranges. Carrier phase measurement is rare included. The other systems transmit observations by communication channel - code pseudoranges and carrier phase measurements. The advantage of this manner is simplicity, accuracy and independence on satellite ephemeris. The main disadvantage is a greater volume of transmitted data. This disadvantage can be suppressed by effective data formatting.

Data protocol recommended by RTCM SC104 [2] is the most spread standard for DGPS in real time applications. The most of code-DGPS receivers is compatible with RTCM messages of types 1 or 9. Special messages (18-21) were designed for more precise techniques (RTK), but these are used rare. These messages contain carrier phase measurements, both pseudorange and correction forms are supported. Insufficient parity protection will be replaced by 24-bit CRC protection in future [4].

As a main standard for postprocessing (i.e. not real-time) DGPS purposes is used RINEX (Receiver Independent Export) created by the Astronomical Institute of University in Bern. It is a readable text format verified during a long period of time. There is a certain possibility for extension and adaptation of this format for the future. RINEX is not generally suitable to transmission in real-time radio link due to a huge data volume. CRINEX (Compact RINEX, packed form of RINEX) created by Yuki Hatanaka in 1996 reduces the data volume three times approximately. RINEX and CRINEX are very spread data formats for postprocessing, but they are not suitable for real-time applications. The fundamental idea of CRINEX compression is interesting for real-time data compression. We use this idea in our protocol design.

As a good example of data protocol intended for high accuracy real-time measurement (RTK) may be declare CMR or CMR+ (Compact Measurement Record Format) designed by Trimble. Although it is a proprietary protocol, it is open for public. This protocol is optimal for the minimal latency at appropriate channel with limited throughput, but it is non-optimal for GSM-GPRS channel, which requires minimal cumulative data volume.

At last years, the Internet data channel starts to be used for DGPS purposes. In 2000 Wolfgang Rupprecht implemented the first version of DGPS Internet server DGPSIP. This technique is based on data transmission in RTCM-SC104 format through TCP or UDP connection. Data protocol of DGPSIP programs available in this time (Jul 2002) is relative simple and not effective enough. More sophisticated protocol version is under development. DGPSIP is usable for GSM-GPRS connection too, but data bandwidth efficiency is not very good for actual protocol version.

4. IDEA AND REALISATION OF DGPS PROTOCOL DESIGN

Two protocol variants of compressed data of GPS observations were defined. The first one is more general and adaptable with good compress ratio, but its compress algorithm is complicated and represents considerable numerical load. Design of the protocols is not completed yet.

The second protocol is primary designed for GPS receiver Garmin GPS-35 (but it is independent on particular receivers type) and contains phase and C/A code observations on GPS L1 band. This protocol is optimised for static or slowly moving user or reference station. For its main advantage - implementation simplicity - the algorithm was designed for small eight-bit microcontrolers. The protocol is intended for raw pseudoranges data transmission from mobile client to server in reference station. The core of redundancy reduction algorithm expresses Fig.1.

The input of this algorithm is a separate satellite observation set in discrete time k, which contains:

- C/A code measurement (pseudorange) $C_1(k)$ recalculated to carrier wavelength,
- Carrier integrated phase measurement $L_1(k)$,
- Signal to noise ratio $SNR_1(k)$ as a signal quality indicator.

As a first step the "code-phase" difference $X_1(k) = C_1(k) - L_1(k)$ is computed. By this step a correlation between $C_1(k)$ and $L_1(k)$ measurements is reduced.

Data volume can be reduced significantly by quantization. The acceptable information loss was assigned by observation record analysis and was verified by quantization impact on accuracy and reliability of resultant position information

$$\begin{aligned} L(k) &= \text{floor}[L_1(k)/\Delta L]\cdot \Delta L \\ X(k) &= \text{floor}[X_1(k)/\Delta X]\cdot \Delta X \quad , \\ SNR(k) &= \text{floor}[SNR_1(k)/\Delta SNR]\cdot \Delta SNR \end{aligned} \tag{1}$$

where function floor() symbolises truncating to lower integer value and the quantization intervals are specified for Garmin GPS-35 (λ is L1 wavelength):

$$\Delta L = \frac{\lambda}{1024}, \quad \Delta X = \frac{\lambda}{4}, \quad \Delta SNR = 3\ [\text{dB}]. \tag{2}$$

As the next step, the time series decorrelation can be applied. This technique is very well known from CRINEX compression. It is based on computation of time series difference.

$$\begin{aligned} dL(k) &= L(k) - L(k-1), \\ d^2L(k) &= dL(k) - dL(k-1) = L(k) - 2L(k-1) + L(k-2), \\ d^3L(k) &= d^2L(k) - d\ L(k-1) = L(k) - 3L(k-1) + 3L(k-2) - L(k-3). \end{aligned} \tag{3}$$

The time series difference for $X_1(k)$ and $SNR_1(k)$ are computed analogically.

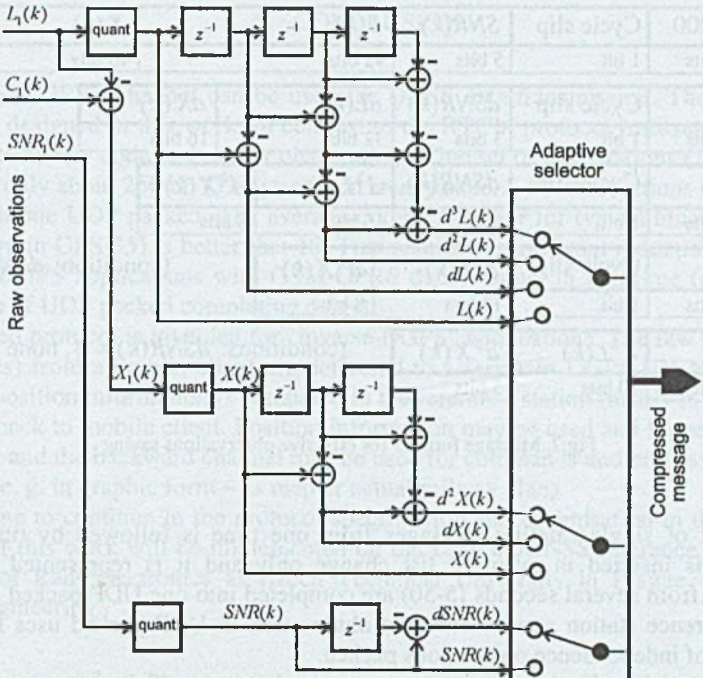

Fig.1. The data processing chart for redundancy reduction (separate satellite observation record)

The final operation is message formatting. Separate satellite observation coding is provided at first. Five message formats were designed; each format has specific range of values and order of time differences. The **F0** format contents full information without relation on previous messages. This format is intended for initialisation or singular events. The **F3** or **F4** formats (bandwidth saving formats) are usable in compression process steady state. The second or third time series difference $d^2X(k)$, $d^3L(k)$ are used in these formats for redundancy saving.

F0:

11100000	Cycle slip	$SNR(k)$	$L(k)$	$X(k)$
ID – 8 bits	1 bit	5 bits	42 bits	40 bits

F1:

1101	Cycle slip	$dSNR(k)$	$dL(k)$	$dX(k)$
ID – 4 bits	1 bit	3 bits	32 bits	16 bits

F2:

1100	Cycle slip	$dSNR(k)$	$d^2L(k)$	$d^2X(k)$
ID – 4 bits	1 bit	3 bits	16 bits	8 bits

F3: (condition: $dSNR(k) = 0$)

10	Cycle slip	$d^3L(k)$	$d^2X(k)$
ID – 2 bits	1 bit	13 bits	8 bits

F4: (conditions: $dSNR(k) = 0$, none cycle slip)

0	$d^3L(k)$	$d^2X(k)$
ID – 1 bit	10 bits	5 bits

Fig.2. Message formats for effective observations saving

The set of single satellite messages from one time is followed by time mark. The satellite list is inserted in event of list change only and it is represented by bit mask. Observations from several seconds (5-50) are completed into one UDP packed and sent from client to reference station server. The first observation in UDP packed uses format **F0** for acquirement of independence on previous packed.

The protocol design represents a compromise between efficiency and robustness. The robustness is needed by virtue of UDP channel irresponsibility. The possibility of retransmission of dropped data is ensured by challenges sent through the Internet/GPRS backward channel. Therefore, the error-correcting coding is not necessary; the UDP protocol error detecting is adequate. One set of observations (one second) for twelve satellites represents approximately 250 bits in steady state. This fact signifies a considerable data volume saving compare to original binary data from GPS receiver (see Tab.1).

Table 1

Compress efficiency of designed algorithm (Results of verification tests, receiver Garmin GPS-35, size of IP and PPP heads and checksums is not included)

Message format	Experiment 1 (static)	Experiment 2 (kinematics)
Relative count F0 [%]	1.17	3.06
Relative count F1 [%]	1.95	2.44
Relative count F2 [%]	5.93	4.51
Relative count F3 [%]	19.84	49.60
Relative count F4 [%]	71.1	40.39
Original record size [byte]	6 280 000	670 675
Compressed record size [byte]	494 719	50 782
Compress factor	12.69	13.2

5. CONCLUSION

The GSM-GPRS channel can be used for DGPS data transmission. The suitable data protocol was designed in this work. In contrast to the RTCM protocol (messages 1 or 9) this protocol contains raw code and carrier observations. One set of observations (12 satellites) is described by only about 250 bit (32 bytes) at in steady state. 5-50 observations (seconds) may be stored into one UDP packed. The average compress factor for typical binary observation protocol (Garmin GPS-35) is better that 10. This results in significant reduction of operation expenses in DGPS applications with GSM-GPRS data channel in real-time (or nearly-real-time, because of UDP packed completing delay).

Designed protocol is intended for „inverse DGPS" applications. The raw measurements (pseudoranges) from a mobile client are delivered to a server in DGPS (DGNSS) reference station. The position information is computed in the reference station (nearly in real time) and may be sent back to mobile client. Position information may be used and logged in reference station server and the backward channel may be used for commands and processed navigation information (e. g. in graphic form – as map or actual railway plan).

We plane to continue in the protocol specification and optimisation in the future. The application of this work will be implemented on the DGPS/DGNSS reference station on the Department of Radioelectronics at Czech Technical University in Prague, at Faculty of Electrical Engineering.

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