

Navigation Capabilities of Future Mobile Communication Systems - will Global Navigation Satellite Systems become obsolete ?

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Abstract

The third and fourth generation *personal communication systems* (PCS) are going to be based on spread spectrum techniques. This article intends to show, that the signal structures used by these systems are very similar to the ones used by GPS and proposed European satellite navigation systems and can be used for the purpose of user localization. Various methods for determining the user position within a PCS are described. Following the concept of hierarchical cellular communication, hierarchical navigation is proposed.

The mutual benefits of a *global satellite navigation system* (GNSS) and a PCS are emphasized.

1. Introduction

The world of navigation sees a new iteration. Up to now GPS and GLONASS have been the only worldwide available systems for localization needs. Their navigation signals are provided under the well-known restrictions, though. With the recent commitment of the European Union to develop its own GNSS (Galileo) the availability and integrity of the navigation signal is supposed to be guaranteed in the future.

At the same time a worldwide move from current (second generation) mobile communication system standards such as GSM, towards a *third generation personal communication system* (3G PCS) takes place. For these upcoming communication systems, user localization, originally a GNSS's task, is becoming a key issue.

The demand for user localization solutions stems from different objectives.

1. Navigation as an "end product"

Providing navigation information to the end-user is a growing market. Car and personal navigation systems show sizeable growth rates.

2. Enhanced emergency services

In the United States the Federal Communication Commission (FCC) requires wireless network operators to provide user localization in the case of emergency calls. This will be required by other nations' authorities soon. Specifications for the resolution and accuracy of this localization will become more demanding in the near future [Rap96].

3. Increasing communication capacity

To increase communication capacity of the future PCSs a promising approach is to exploit knowledge of the users' position in order to use adaptive directive antennas to reduce interference from (and upon) other users.

1.1. How to distinguish between navigation and wireless communication systems ?

There is no clear borderline between navigation and wireless communication systems. Current navigation systems provide a certain amount of broadcast information such as ephemeris data, satellite condition and other navigation related data. Ongoing discussions on future systems (e.g. Galileo) seem to indicate that the amount of broadcast information will be considerably extended.

On the other hand the inherent localization capabilities of communication radio signals have been exploited since the beginning of the existence of wireless communication. In the pioneering times of radio navigation, this was achieved mainly by determination of *the angle-of-arrival* (AOA) of the received radio signals and triangulation. Later, dedicated navigation systems like DECCA, TACAN, DME, LORAN and OMEGA made use of the finite speed of electromagnetic waves.

With the advent of spread spectrum communication systems, the improved ability to determine the differences in the *time-of-arrival* (TOA) of the incoming signals further enhanced the localization capabilities. The *Joint Tactical Information Distribution System* (JTIDS) is an example of a communication system with excellent relative-navigation capabilities. The purpose of this system really is split between navigation and communication [Ran96].

One could say, that the classification into navigation or communication system can only be made by a look on the purpose a system is used for, not even by what it was designed for.

In the following we intend to show that the signal structure proposed in the *ESA Signal Design Study* (ESA-SDS) and proposed third generation PCS (UMTS/IMT-2000) signal structures do have similarities that suggest the use of PCSs for localization purposes.

2. Comparison of Signals

2.1 ESA-SDS [Sch98]

2.1.1 Spreading

One of the main goals in designing navigation systems is accuracy. A basic rule states, that the achievable accuracy is proportional to the signal's bandwidth. Large parts of the frequency bands currently assigned to navigation are already occupied by GPS and GLONASS. Since these systems had the luxury of large frequency slots at the time they were designed, they didn't have to be optimized to the outmost. The Galileo system will have to cope with far less resources in terms of bandwidth. Only three small slots of 3.68 MHz each, are available in the dedicated band. In the style of GPS, the ESA-SDS signal is generated by direct sequence spreading of the spectrum.

In order to fit into the frequency slots (E1, E2, E4) a chiprate of 3.069 MChips/s is proposed in the study. Gold sequences of length 1023 are chosen among other reasons for their good correlation properties as spreading codes. Due to complex-valued spreading, each satellite occupies two distinct sequences out of the $1023 \cdot 2$ possible sequences.

2.1.2. Pulse Shaping

In contrast to the prevailing GPS which uses filtered rectangular pulses, the ESA-SDS signal was optimized for maximum performance within the given bandwidth. With the chosen root-raised-cosine pulse shape and rolloff-factor $r=0.2$ the navigation signal occupies a bandwidth of 3.68 MHz.

2.1.3. Frequency Allocation

As already mentioned, bandwidth is a scarce and therefore precious resource, especially for a new GNSS in L-Band. Thus, the signals proposed within the ESA-SDS have to fit into the above mentioned slots E1, E2 and E4. The corresponding carrier frequencies are 1589.742 MHz, 1561.096 MHz and 1256.244 MHz. The three slots are 3.68 MHz wide each.

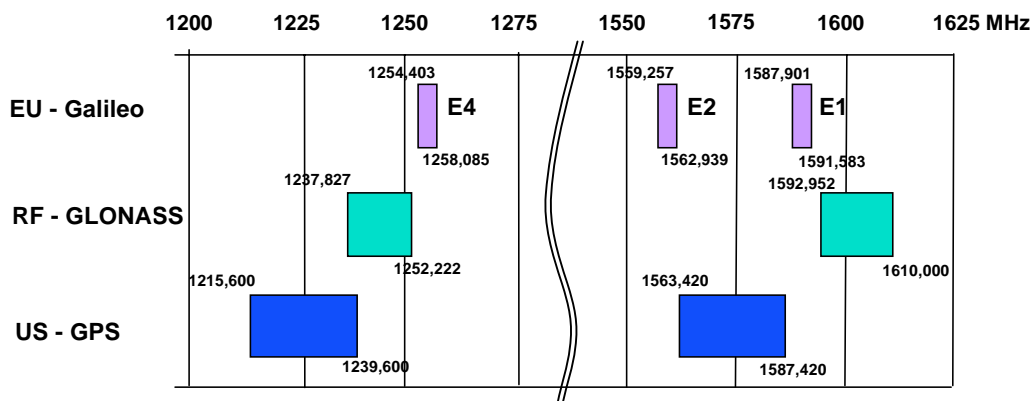


Fig 1 Frequency allocation for Global Navigation Satellite Systems

2.2. UMTS/IMT-2000

Global efforts are being made, in order to produce worldwide accepted standards for *International Mobile Telecommunications (IMT-2000)*. Due to the ongoing standardization process it would be wrong to talk of "the" IMT-2000 signal structure. Apart from the *European Telecommunications Standards Institute (ETSI)* proposing the *Universal Mobile Telecommunications System (UMTS)*, Korea (TTA), Japan (ARIB) and China (RITT) as well as the US (TIA and T1P1) have defined regional standards and made similar proposals for the air interface. Though the final decisions on global standardization will be made by the *International Telecommunication Union (ITU)*, harmonization between the different proposals is desirable. For this purpose the *Third Generation Partnership Project (3GPP)* has been founded. The above mentioned groups are members or observers of this project, which has the objective to co-operate for the production of technical specifications for a *third generation personal communication system (3G PCS)* that the organizational partners support. Such a harmonized specification will necessarily be some kind of compromise between the existing proposals. Since the scope of this presentation is to investigate the key features of an IMT-2000 signal and its potential for localization purposes, the finer differences of the various proposals are neglected in this paper.

Therefore, the key-features of a "likely" IMT-2000 signal are described in the following.

2.2.1. Spreading

Data rates for the first implementation of UMTS will be 144 and 384 Kbits/s. For these rates a chiprate of 4.096 Mchips/s is intended, which results with the pulse-shaping described in 2.2.2. in a bandwidth of approximately 5 MHz. Higher chiprates (8.192 Mchips/s, 16.384 Mchip/s) resulting in larger bandwidths of up to 20 MHz are proposed in order to sustain even higher data rates more effectively.

We see that chiprate and bandwidth are even higher than in the proposed ESA-SDS-signal.

2.2.2. Pulse Shaping

In order to harmonize UTRA's *Time Division Duplex (TDD)* and *Frequency Division Duplex (FDD)* mode the original concept of implementing linearized *Gaussian Minimum Shift Keying (GMSK)* for the TDD mode has been dropped and from today's perspective the pulse shape is a quite fixed parameter. Root-raised-cosine with a rolloff-factor $r=0.22$ is selected.

In addition to the high bandwidth and the same pulse shape, a rolloff-factor that is optimum for navigation purposes is used.

2.2.3 Frequency Allocation

Frequency allocations for UMTS/IMT2000 are separated into two regions of the spectrum. One is ranging from 1850 MHz to 2025 MHz; the other from 2110 to 2200 MHz. Certain variations exist within the various local regulations. Especially in North America the lower region is quite fragmented by allocations for different legacy systems.

It can be stated, though, that the signals are going to be located in the transit zone from L-Band to S-Band.

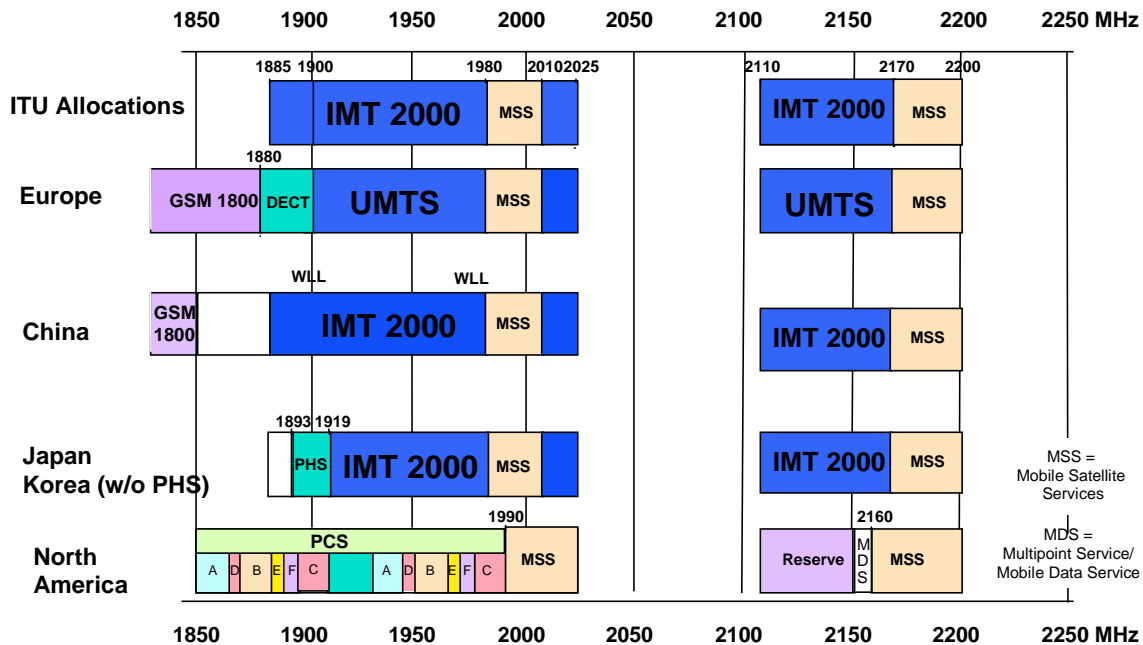


Fig 2 Worldwide frequency allocation for 3rd Gen. PCS. Source: UMTS Forum

Also remarkable are the slots labeled MSS. For this satellite component of the 3G PCSs in both lower and upper spectral region two times 30 MHz bandwidth are provided.

From a propagation point of view the frequency allocation for the typical GNSS signals and the 3G PCS signal is almost identical. 3G PCSs even have more available bandwidth. Considering the satellite component of 3G PCSs the spacing of approximately 200 MHz between the two slots assigned to MSS might even be sufficient for determination and correction of ionospheric effects.

3. Methods for position determination in Personal Communication Systems

The position determined by using a PCS is obviously not global. The base stations have to provide information about their positions in order to match the relative grid to the global grid.

Unfortunately multipath propagation causes the same problems for PCS-based position determination as it does in satellite navigation. Numerous and still improving mitigation methods exist for that problem. Continuing research in that field is considered a key issue in improving accuracy of both GNSS- and PCS-based position determination.

In contrast to a GNSS, various principles for estimating the user's position exist for a PCS. They will be described and classified in the following.

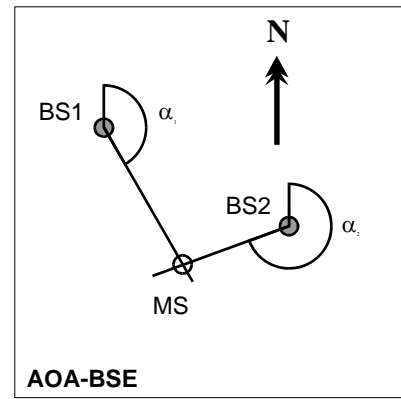
3.1. Angle-of-Arrival

Due to the use of multiple-element antennas at the base stations it is possible to estimate the *angle-of-arrival* (AOA) of incoming signals. In principle two AOAs are sufficient to determine the user's position (under the assumption, that the user is at ground level).

To classify the different kinds of possible estimations we call this an *angle-of-arrival-at-base-station-estimation* (AOA-BSE).

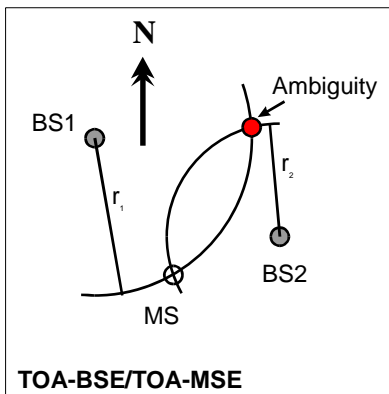
Various methods to estimate the AOA of an impinging signal at a multiple-element or multi-beam antenna exist. They range from simpler ones like algorithms comparing the received power at neighboring antenna beams [Sak92], to more complex and powerful digital signal processing techniques like MUSIC [Sch86], ESPRIT, and a multitude of algorithms derived from them.

The AOA-BSE does not rely on precisely synchronized base stations. This is clearly an advantage due to less stringent requirements on the clocks installed at the base stations. In addition to that no position ambiguity exists. Unfortunately, these advantages are slightly reduced due to the vulnerability of the AOA-BSE to multipath signals impinging from different AOAs, and therefore work best in conjunction with estimations described in the following.

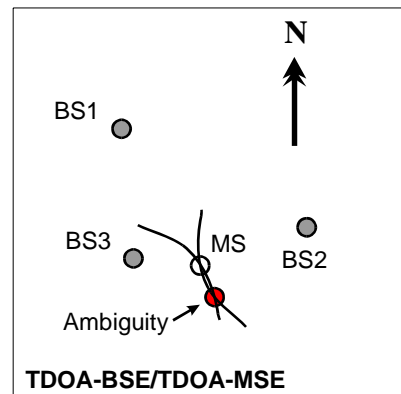


3.2. Time-of-Arrival

In a standard GNSS receiver the relative delays are determined comparing the time-of-arrival of the different satellites' signals. Knowing the position of the transmitters and computing the resulting nonlinear equation system one can solve for the position of the receiver. Almost the same method



used in a GNSS can be applied for localization with a PCS. Assuming perfect synchronization of the *base stations* (BSs) and the *mobile station* (MS) to absolute time, a MS has to measure the time-of-arrival of signals emitted by at least two BSs. Again the resulting nonlinear equation system has to be solved, yielding an estimation for the mobile's position. We call the gathered position knowledge a *time-of-arrival-at-the-mobile-station-estimation* (TOA-MSE). If at least two BSs measure and



compare TOA of the signal emitted by the MS, they can give *time-of-arrival-at-the-base-station-estimation* (TOA-BSE). As uplink and downlink frequencies are different for FDD, we can assume some amount of independence of the TOA-MSE and the TOA-BSE. In practice we usually cannot assume perfect synchronization and knowledge of absolute time. The clocks within the MSs are subject to drifting. In order to cope with that problem a third BS is necessary for an accurate estimation. The BS (MS) then measure only the *time-differences-of-arrival* (TDOA) between the impinging signals. A certain TDOA corresponds to a position of the MS somewhere on a hyperbola. The position of the MS is then calculated by the intersection of two hyperbolas. To be precise one has to denote these estimations TDOA-MSE and TDOA-BSE respectively. For simplicity we classify these methods also as TOA-MSE and TOA-BSE.

3.3. Combining Estimations

The TOA as well as the AOA can only be estimated with finite accuracy. The probability density functions of the errors of the different estimations are either known or can be approximated. By

combining the probability density functions from independent measurements the final estimation can be improved. It can be shown that combining the TOA-MSE, TOA-BSE and AOA-BSE¹, the resulting estimation becomes better than any “single” estimation.

4. Mutual Benefits of GNSS/PCS

- In addition to the previous paragraph it should be mentioned, that combining PCS and GNSS based estimations with their independent errors further improves the achievable accuracy. GNSSs don't work in indoor environment, whereas PCSs do. Here PCSs and GNSSs. can be complementary to each other.
- The hierarchical cellular structure of 3G communication systems can be projected towards a hierarchical navigation structure.
- Determination and correction of ionospheric effects could be improved by combining the measurements possible at the GNSS frequencies and the 3G PCS satellite component frequencies.
- PCS base stations rely on accurate synchronization. Employing GNSS for time distribution is a cost-effective solution for this problem.
- To improve system capacity of a PCS the ability to determine the user position is a key aspect. Whether this will be done by integration of GNSS-receivers into PCS-terminals or by using the inherent localization capabilities of the communication signals will be decided based on market and strategic issues.
- A GNSS provides raw position information. In combination with PCS the value of this information can be multiplied. The PCS can add value to the determined navigation information by adding local aware services, e.g. road information services, weather services and many more.

5. Conclusion

To answer the provocative question of the title: Next generation personal communications systems are not likely to drive GNSS into obsolescence. Instead, navigation and communication systems will form a symbiosis.

References

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¹ Since commercial mobile terminals are not likely to have multiple-element antennas in the near future, an *angle-of-arrival-at-the-mobile-estimation* (AOA-MSE) is assumed not to be available at the time. However, the move towards higher carrier frequencies this might change soon.