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# New ICO, A Proposal for a CDMA Mobile Satellite System

## -An Integration of Cellular, Satellite Communication and Positioning services-

Osamu Ichiyoshi
Human Network for Better 21 Century,
230-7 Kamikuzawa, Sagamihara City, 229-1136 Japan
http://www5e.biglobe.ne.jp/~kaorin57/

**Abstract**

The ICO system was designed to provide global mobile communications with hand-held terminals. The system had a high degree of compatibility with GSM to provide dual cellular and satellite modes mobile services for the users. Unfortunately the project was scrapped in 2000 because the rapid growth of the cellular systems was expected to take most of the intended market. Today, the cellular systems have grown so much that the market is already saturated in many countries. The growth of the cellular market was made possible by adoption of small cells, which enabled the miniaturization of user terminals and higher frequency reuses at the cost of more complex communication controls. Thus further expansion of the services areas to sparsely populated but vast regions is very difficult with the conventional technology.

It seems to the author that the ICO system has a new market potential to further expand the coverage areas and the services for mobile communication. The New ICO, herein proposed has a few features; (1) The CDMA scheme extremely simplifies the communication controls compared with TDMA/FDMA adopted in the Old ICO, (2) The 10 satellites ICO system can enhance the GPS readily by broadcasting a GPS compatible signal for each beam, (3) Dual cellular and satellite mobile system is easily realized for the next generation cellular systems. Another important feature of the proposed system is that most of the system design, Satellite Access Nodes (SAN) earth stations and satellites designs can be reused so the development cost and time can be significantly reduced.

The New ICO system can make effective use of the Old ICO, the cellular and GPS technologies to realize a universal mobile communications services for the 21$^{st}$ century.

**Keywords;**

ICO; Intermediate Circular Orbit, CDMA ; Code Division Multiple Access, SAN; Satellite Access Node

## 1. Introduction

The past ten years of mobile communications can be characterized by the rapid growth of cellular communications and GPS applications. The cellular markets have grown hundreds of times during those years. Today, there are more than 100 million cellular terminals in operation, i.e. almost one unit for everyone in Japan. The market growth was realized by technology development from the FM telephony systems of the first generation to the digital TDMA systems of the second generation and to the higher rates CDMA systems of the third generation. It seems to the author the cellular market has already reached saturation in many countries. The small zone cellular systems that have been effective for miniaturization of the user terminals will be no more effective for further expansion of the service areas especially in rural areas. The expansion of the service areas can be most effectively achieved by the mobile satellite communication. Very wide service areas covering numbers of countries can be easily built.

Another application that takes advantage of the satellite communication is the GPS. The GPS has fully established itself as the global positioning system. However, some problems remain; (1) Since it is a system developed for military purpose, its availability depends on the policy of USA government. (2) The C/A codes open to the public is rather limited in bandwidth (1.023MHz), e.g. positioning precision. It can be improved by the proposed system with wider signal bandwidths. (3) The GPS provides only positioning and no communication service. If positioning and communication services are combined, more useful applications will become possible for users especially in those areas out of cellular communication services. It will be particularly essential for emergency communications.

The New ICO, proposed in this paper, can solve those problems facing the cellular and GPS systems. The wide area coverage of New ICO can expand the service areas to global scales and the multiple satellites configuration can enhance the availability and performances of GPS. The measurement precision can be improved to better than one meter.

## 2. Overview of Old ICO system

### 2.1 Objective of the system

The objective was to provide a global mobile communication for the users with hand-held terminals (smaller than 300 cc and 300 grams). The special feature was adoption of GSM system to ensure dual mode cellular and satellite mobile communications to be easily integrated. Except for the air interfaces which must be quite different corresponding to the radio wave propagation characteristics in terrestrial and satellite links, the system architecture and protocols were based on the GSM specifications. The major services were mobile telephony and data communications (up to 16 kbps) with full paging, location updating and roaming services to and from GSM networks. Short messaging and most of advanced services provided by GSM were supported.

### 2.2 System capacity

- Annual paid minutes of voice traffic; 2.4 billion
- Busy hour paid minutes per year per voice cannel ; 150,000
- Fraction in busiest satellite ; 0.28
- Satellite capacity in voice channel ; 4,500

### 2.3 Space segments

The orbit scheme adopted for ICO system was an intermediate non geo-stationary orbit with the altitude of about 10,355km above the ground. The rotation period is about six hours. In order to provide global coverage a total of 10 satellites on two orthogonal orbits with five satellites each would be used to provide the service. The inclinations of those orbit planes against the equator are + and – 45 degrees. The lower altitude of ICO satellites reduces the propagation loss to 1/10 and the propagation delays to 1/3.6 (75ms for round trip) compared with geo-stationary satellites. Additional gains are achieved by adoption of multiple (163) service link beams. In total more than 30dB gains are achieved against geostationary global beam satellites to make the hand-held communication feasible.

### 2.4. Radio Frequencies and Beams

**[1] Feeder link**

The feeder link is the link between the satellite and SAN earth stations. The frequency bands are C-bands and the beam pattern is global. Thus the satellite is accessible by any SAN within the area where the satellite elevation angle is greater than a threshold (10 degrees).

- Up link frequency ; 5183.1 – 5241.6 (MHz)
- Down link frequency ; 7013.1 – 7071.6 (MHz)

Both right-hand circular (RHCP) and left-hand circular (LHCP) polarizations are used.

**[2] S-band Service link**

The service link consists of 163 spot-beams and uses parts of 30MHz in S-bands. The beam routing and frequency setting are possible independently. The service link frequency bands are;

- Down link (Forward Link) ; 2170-2200 (MHz) RHCP
- Up link (Return link) ; 1985-2015 (MHz) RHCP

**2.5. Satellite Coverage Performances**

The satellites configuration of ICO system guarantees at least one satellite is visible anywhere with elevation angles greater than 20 degrees. The average elevation of the satellites is about 40 degrees. A feature is that there are at least two satellites visible with elevation greater than 10 degrees almost everywhere most of the time.

**2.6. Signal transmission subsystems**

**[1] Multiplex methods**

The multiplex method was TDMA/FDMA. The TDMA frame length was 40 ms. The number of time slots in a TDMA frame was 6. The channel spacing for the FDMA was 25 kHz.

**[2] Modulation**

The modulation speed was 36ks/s (18kbaud). The modulation type was QPSK for the forward link and GMSK for the return link.

**[3] Voice coding**

The Multi-band-excited (MBE) code was adopted. The coding gives communication quality voice for 4.8 kbps with 4% bit errors. The voice coded data of 192 bits/frame (40ms) was formed into 240 bits burst /frame (6 kbps). The symbol rate was then converted to 36 ks/s for burst formation for the TDMA of 6 time slots.

**[4] Synchronization**

The TDMA synchronization was made against ICO System time which was based on GPS time. All SAN earth stations were equipped with GPS receiver to establish ICO system time. The SAN compensated her transmit timing of the bursts so the bursts reach exactly at the designated ICO System time at the center of the beam where the target user terminal (UT) exists. The UT establishes its timing by receiving the signal from the SAN. The return link timing adjustment was made by the UT following the commands from the SAN. Thus the TDMA synchronization was made by open loop for the forward link and by a closed loop for the return link.

The frequency control was also required because the Doppler shifts at the L bands reached almost 10 kHz at the distant (edge) beams. The SAN compensated her transmit frequency so the frequency will become exact at the center of the target beam. The UT established its frequency by the received signal and compensated the transmit frequency following the controls given by the SAN.

**2.7 Link Power budget**

The forward and return links power budgets are given in Table 2.7-1, 2. The number of traffic channel carriers is 750. In addition were 15 control channels carriers. Sufficient link margin of 8.0 dB was given. Most of the satellite power was dedicated for the forward link. The total S-band EIRP was about 60dBW. The antenna gain of the 163 beams was about 30dB. Thus the total S-band RF power was 1kW. The DC power for the satellite transponder was about 3 kW.

**2.8 Hand over operations**

**[1] Beam hand-over**

The rotation period of ICO satellites is 6 hours, or 6,700km per hour on the ground. The smallest beams right below a satellite are about 400km in radius. Therefore very frequent beam hand-over (once every 4 minutes) is required.

**[2] Satellite hand-over**

The User Terminals in communication with the edge beams needs a satellite hand-over as the satellites in use moves away from the area.

**3. Technical Problems with Old ICO**

**[1] Complexity in Frequency allocation**

The coverage areas of ICO satellites overlap. The overlapping between the satellites on the same plane is fixed, but the overlapping between different planes constantly changes. In addition, the traffic distribution on the ground is very biased and change with time. Therefore allocation of the frequency resource to each beam of each satellites achieving efficient matching with the changing traffic distribution required a very complex processing. Distribution of the frequency allocation plan to all SAN earth stations was also cumbersome. The complexity was especially a problem to meet emergency cases.

**[2] Complexity in Hand-over**

The above hand-over operations were also complex and also very frequent. Constant prediction and hand-over process controls required very complex operations.

Those complexities made the development work of the system difficult.

Table 2.7-1 Return Link Power budget

| | |
|---|---|
| Number of service link spot-beams | **163** |
| **Up-link** | |
| Up-link frequency (GHz) | 2.01 |
| **UT EIRP per carrier (dBW)** | **6.8** |
| **Free space loss (dB)** | **181.1** |
| **Satellite mobile link G/T (dB/K)** | **3.5** |
| **Propagation margin (dB)** | **8.0** |
| **Up-link C/No (dB.Hz)** | **49.7** |
| | |
| **Down-link** | |
| Down-link frequency (GHz) | 7.025 |
| **Satellite EIRP per carrier (dBW)** | **-6.0** |
| **Path loss (dB)** | **192.9** |
| **SAN G/T (dB/K)** | **31.0** |
| **Propagation margin (dB)** | **3.0** |
| **Down-link C/No (dB.Hz)** | **57.7** |
| | |
| **Overall** | |
| **Satellite C/IMo (dB.Hz)** | **65.3** |
| **Satellite link total C/No (dB.Hz)** | **49.0** |
| **Interference allowance (dB)** | **1.0** |
| **Overall C/No (dB.Hz)** | **48.0** |

Table 2.7-2 Forward link power budgets

| | |
|---|---|
| **Up-link** | |
| **Up-link frequency (GHz)** | **5.2** |
| **EIRP/carrier (dBW)** | **49.7** |
| **Free space loss (dB)** | **190.2** |
| **Satellite feeder link G/T (dB/K)** | **-17.0** |
| **Propagation margin (dB)** | **2.0** |
| **Up-link C/No (dB.Hz)** | **69.1** |
| | |
| **Down-link** | |
| Number of S-band beams | 163 |
| Down-link frequency (GHz) | 2.2 |
| **Satellite EIRP/carrier (dBW)** | **34.3** |
| **Free space loss (dB)** | **181.9** |
| **Atmospheric loss (dB)** | **0.1** |
| **UT G/T (dB/K)** | **-23.8** |
| **Propagation margin (dB)** | **8.0** |
| **Down-link C/No (dB.Hz)** | **49.1** |
| | |
| **Overall** | |
| **Satellite link C/No** | **49.0** |
| **Interference allowance (dB)** | **1.0** |
| **Overall C/No (dB.Hz)** | **48.0** |

## 4. Features of New ICO

The New ICO proposed here is based on the above consideration. The features of the proposed systems are;

**[1] CDMA Simplifies Communication Control**

Because the separation of channels is made by differentiation of PN codes, the whole system can share the same frequency bands. Therefore frequency allocation process is the most simplified. The hand-over processing is also much simplified. Only the SAN earth stations conduct the hand-over operations with minimal involvement of the user terminals (UT).

**[2] Compatibility with next generation cellular NW**

The CDMA is suitable for development of dual mode cellular and satellite user terminals.

**[3] Enhancement of GPS**

By supplying GPS compatible signals through the satellites, the New ICO can enhance the availability and reliability of GPS. For more details, see Ref [2].

**[4] Reuse of Old ICO Design and Systems**

The satellites configurations, SAN distributions, system design of the satellite links and terrestrial networks, SAN facilities and most of satellites subsystems can be reused. Therefore the development work will be made much more efficiently.

## 5. New ICO System

### 5.1 Reused and Replaced Subsystems of the Old ICO

The satellites configuration, the multi-beam antennas of the satellites, the satellite link power budget, the RF subsystems of SAN earth stations, the inter-SAN network (ICONET) and so on will be reused with very small modification if any.

The multiplex system will be totally replaced by CDMA. The associated communication controls will be naturally totally replaced. GPS enhancement schemes will be added.

### 5.2 System Description of New ICO

**[1] Services**

The major services are mobile telephony and data communications. Dual mode operations between the satellite and cellular systems will be supported. Depending on the contracts with the cellular system operators, full roaming service will be provided for the relevant users. The communication will be basically circuit switched demand assign communications. The packet switched random access is TBD.

**[2]Frequency Allocation**

The frequency allocation will be ROFA (Region Oriented Frequency Allocation) instead of SOFA (Satellite Oriented Frequency Allocation) in the Old ICO system.

The ROFA allows the user to use the frequency bands allocated to mobile satellite services specifically in the area the user is currently located. This simplifies the regulation procedures and can increase the system capacity. The SAN uses C bands and the UT uses S bands just as in the Old ICO system. It is expected that the New ICO can use continuous 10MHz bandwidth within the total 30MHz planned for the Old ICO. However complex the regulated frequency allocation may be, the ROFA frequency allocation processing can be static in normal situations.

**[2] CDMA and Modulation**

The CDMA (code division multiple access) is used for both forward and return links. Major parameters are

- Modulation; BPSK
- Modulation rate; 10 kBaud
- Chip rate; 1.023 MHz
- Code length; 1,023

The modulation speed of 10 ks/s in the proposed New ICO is significantly smaller than 36ks/s in Old ICO. About 5.6 dB additional margin is obtained in the link power budget.

### 5.3 Hand-over Operations

**[1] Beam hand-over**

This is the most frequent operation. The movement of the satellite requires beam hand-over at least once every 5 minutes. In the New ICO the user terminals (UT) has minimal involvement in the beam hand-over. Actually the UT continues communication with the allocated PN code during the communication without noticing the beam hand-over at all. The SAN conducts all the beam hand-over operations as follows. The SAN allocates a PN code to a UT through the same beam the UT sent Access Request signal. During the communication the SAN keeps monitoring the location of the UT relative to the beams. The SAN monitors the signal from the UT through the currently communicating beam and the adjacent beams that are expected to carry the signals after the beam hand-over. Normally the SAN conducts correlation detection for the target code through two or three adjacent beams.

The required processing capacity for a SAN is assessed as follows. The number of simultaneous communications handled by a SAN is supposed to be 3,000 and the number of beams to be checked is 3. Then the required number of PN correlation detection is therefore 9,000 operations. On the other hand the correlation of the PN codes of 10MHz chip rate and 1,023 chips length takes 0.1 ms for one processing. Even if some ten repetitions for each correlation are made to increase the reliability, it takes only 9 seconds for monitoring all the ongoing communications. A SAW PN correlation device (Ref[2]) can realize a real-time processor with a small size for the above processing.

The beam switching is made by the SAN. The SAN receives the signal from the UT through nominally 3 beams. The redundant receiving can be combined to improve the C/N ratio of the receive signal. The SAN sends the forward link signal through the beam that gives the best C/N performances. Thus the SAN conducts communication and beam hand-over by communicating with the UT through 3 relevant beams. The hand-over is simply selecting the best beam for sending the signal from the SAN. The UT does not even notice if the beam hand-over is made at all.

**[2] Satellite hand-over**

This becomes necessary when the satellite through which the communication is going on will move out of sight of either of the parties and another satellite is available that gives a common view for both parties. This is made by the SAN by switching the RF subsystem. The UT does not have to do any special hand-over operations.

**[3] Inter-SAN hand-over**

This becomes necessary when the SAN and UT are very far from each other and the satellite through which the communication is going on will soon leave the area and no other satellites gives a common view to the SAN and IT. This requires inter-SAN hand-over through the ICONET as was specified in the Old ICO.

This is a very rare event and can be reduced by defining proper service areas for the SAN earth stations.

### 5.4 Satellite diversity

The major fading in mobile satellite communications is on-off shadowing by buildings, trees and environments. As two satellites are visible almost anywhere and most of the time in ICO system, the satellite diversity can be offered to improve the quality of communication. The SAN monitors the signal from the UT through two satellites visible from the UT location. The SAN can tell which of the satellites gives better propagation quality from the reception and send its forward link signal through the better satellite link. The diversity can improve the quality of service.

### 5.5 GPS Enhancement

The 1,023 Mega chips per second is the same rate as GPS Precision (P) codes. The New ICO can send GPS compatible signals for enhancement of GPS. Two ICO satellites are visible almost anywhere most of the time. Combined with GPS, the New ICO system can enhance the availability of GPS services. The precision codes bandwidth of 10MHz corresponds to 100ns chip length. For slowly moving users a DLL (Delay Lock Loop) in the receiver can achieve down to a few degrees phase error, improving the time measurement to about 1 ns, which corresponds to only 0.1 meter in positioning error. Thus a significant enhancement of GPS accuracy can also be achieved. For fast moving vehicles the SAW (Surface Acoustic Wave) PN correlation device(Ref[2]) can give fast (once every 0.1 ms) and sufficiently accurate (better than 10 meters) measurements. The SAW device is also quite useful for miniaturization of user terminals (UT).

## 6. Communication Capacity of New ICO

**[1] Required C/No**

In the Old ICO, the modulation rate was R(old) = 36ks/s = 45.6dB.Hz. The worst C/No condition was designed at C/No = 48.0dB.Hz. In the worst condition, Es/No = C/No – R(old) = 2.4dB. In the clear sky condition C/No = 48.0 + 8.0 (margin) = 56.0dB/Hz and Es/No = 10.4dB.

In the New ICO, the modulation rate is R(new) = 10ks/s = 40.0dB.Hz. If we apply the same worst Es/No = 2.4dB, then the minimum C/No = 42.4 dB/Hz. The difference in the symbol rate $\delta R$ = 45.6-40.0 = 5.6dB = 3.63 can be used as follows.

**[2] Return link**

The return link C/N condition is determined by the EIRP of the UT and the G/T of the satellite. The symbol rate difference $\delta R$ = 5.6 dB can be used to reduce the EIRP of the UT from 6.8dBW to 1.2dBW. At the same time the number of the carriers can be increased to 750 x 3.63 = 2,722 for the same satellite power consumption.

**[3] Forward link**

The rate difference $\delta R$ can be used to increase the number of carriers to 2,722 for the same power consumption of the satellite.

**[4] Additional coding gain**

In the Old ICO, the original 4.8kb/s was coded to 6kb/s. In the new ICO, further rate increase to 10kb/s is made. This extra rate expansion can be used to implement more powerful cannel coding so the BER performances can be improved for the same Es/No condition.

**[5] Constraints in traffic distribution**

The processing gain in the New ICO is about 30dB (1,023). In order to secure C/I greater than 10dB, the number of carriers in a beam needs to be at most 100. As the number of carriers increase the C/I decreases. For 200 carriers the C/I become 7dB. As two satellites are visible anywhere most of the time, about 400 calls over areas with 1,000km diameter (average beam size) can be served. This is sufficient as the role of the New ICO system is complementary for the cellular systems.

## 7. Conclusion

A satellite mobile communication system titled New ICO is proposed. The New ICO reuses most of the system designs and facilities (if available) of the Old ICO except for the multiplex system. The TDMA/FDMA multiplex system of the Old ICO will be replaced by CDMA. Adoption of CDMA extremely simplifies the communication control operations in the frequency allocation procedures, timing synchronization and beam and satellite hand-over operations. The CDMA scheme is effective for integration of the New ICO system with the next generation cellular mobile communication systems. The Roaming system of the Old ICO design can be effectively reused there. The CDMA scheme is also used for enhancement of GPS with the multiple satellites of the ICO system. Improvement can be achieved in both availability and reliability with the increased precision of positioning. The proposed New ICO can provide somewhat smaller channel capacity for the same power of the same satellite designed for the Old ICO. This will be sufficient for the New ICO that serves those areas not covered by the cellular systems that have grown so much since the Old ICO plan was scrapped about seven years ago.

The reuse of the Old ICO system will significantly reduce the development work of the New ICO system. The New ICO system integrated with the cellular communication networks and the GPS will provide the mobile communication users with enhanced capacity, universal coverage and improved positioning capabilities.

## References


[1] ICO System Definition, Version 6, December, 1995

[2] Takaya Watanabe, Osamu Ichiyoshi "Time and Frequency Accuracy Requirements for an Enhancement of GPS with GEO Satellites", Paper No.7174, EFTF, Geneva May-June, 2007