Comparison between CDMA and TDMA Air Interface for Cellular Systems

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Abstract
Second Generation (2G) mobile cellular communication systems, which use digital technology, are very successful worldwide. This paper discusses the basic important properties of different multiple access technologies used for cellular systems. Main focus is on two popular systems: time division multiple access (TDMA) and code division multiple access (CDMA), highlighting the advantages of each individual system. Factors that affect capacity on the two systems are considered to compare their spectrum efficiency. A brief overview on 3G systems is also included.

1. INTRODUCTION
A mobile cellular communication system provides a wireless connection to the public switched telephone network (PSTN) for any user located within the radio range of the system [1]. Due to the continual advancement in digital and RF circuit fabrication, cellular phones are getting more popular and affordable.

In cellular communications, the choice of multiple access is one of the most important issues. There are three important basic properties of a multiple access. The properties are flexibility, quality and capacity [2]. Operational flexibility includes easy frequency/cell planning. Abilities to operate in different environment provide different services for different cell types and users to support coexistence with other systems. Quality will include good speech quality. This can be determined by a subjective test, usually based on a subjective mean opinion score to determine the required carrier-to-interference ratio (C/I) [3]. Quality will also include good coverage to provide the service to users on demand and reliable communication in terms of low number of dropped calls. High capacity radio access is vital for cellular radio because it ensures maximum efficiency for the limited and expensive spectrum. This paper discusses the basic important properties of different multiple access technologies used for cellular systems. Main focus is on two popular systems: time division multiple access (TDMA) and code division multiple access (CDMA), highlighting the advantages of each individual system.

This paper is organized as follows: section 2 presents an overview of cellular systems. Section 3 compares the multiple access technologies between TDMA and CDMA. Section 4 briefly describes third generation cellular systems. Conclusions are provided in section 4.

2. OVERVIEW OF CELLULAR SYSTEMS
The evolution of mobile cellular communications can be found in [1], [4]. The ability to provide wireless communications to entire population was developed in the 1960s when Bell Laboratories developed the cellular concept: concept of dividing a large coverage zone (market) into small cells. The same spectrum can be reused by different cells, which are separated by a minimum reuse distance, to increase spectrum usage. First generation of cellular systems was implemented in the late sixties till the late eighties with analog systems using frequency division multiple access (FDMA). Popular systems examples include Advanced Mobile Phone System (AMPS) in the US, European Total Access Cellular System (ETACS) in Europe and Nippon Telephone (NTT) system in Japan.

Today cellular network are generally called second generation or 2G technologies that conform to the 2G standards. 2G standards use digital modulation formats and TDMA/frequency division duplex (FDD) and CDMA/FDD multiple access techniques. The most popular 2G standards include three TDMA standards and one CDMA standard: a) Global System Mobile (GSM), which is widely used in Europe, Asia, Australia, South America and some parts of US; b) Interim Standard 136 (IS-136), which is also known as North American Digital Cellular (NADC) and popular in America; c) Pacific Digital Cellular (PDC), which is a Japanese TDMA; d) Interim Standard 95 Code Division Multiple Access (CDMA) or cdmaOne, which is widely developed in countries such as North America, Japan, China, South America and Australia.
Data transmission in 2G is generally limited by the user’s data throughput rate and is not sufficient to support modern Internet applications. Thus, 2.5G systems, which are compatible to 2G and able to support the popular web browsing format language, Wireless Applications Protocol (WAP) is introduced.

2. COMPARISON BETWEEN CDMA AND TDMA

Multiple access techniques can be grouped into wideband and narrowband systems [1] are used to allow many mobile users to share simultaneously the finite amount of radio spectrum. This must be done without severe degradation in performance of the system, so as to provide high quality communication. As present and future standards are based on TDMA and CDMA standards, it is worthwhile to do a comparison between the two popular multiple access systems.

2.1 Main Features of TDMA Systems

In TDMA systems, the radio spectrum is divided into time slots and in which time slot only one user is allowed to either transmit or receive as shown in Fig. 1 [1].

Transmission for any user is non-continuous as TDMA transmit data in a buffer-and-burst method. Each channel can be view as a particular time slot that re-occurs every frame, where N slots comprise a frame. Fig. 2 [1] shows a typical TDMA frame.

2.2 Advantages of TDMA Systems

The non-continuous transmission characteristic of TDMA has posed several advantages over other multiple access techniques [1]. Since the subscriber transmitter can be turned off when not in used, this results in low battery consumption. The handoff process is also made much simpler, since the mobile is able to detect for other base stations during idle time slots. Duplexers are not needed as TDMA uses different time slots for transmission and reception. For TDMA/FDD only an addition switch is needed to switch between transmitter and receiver respect to CDMA. TDMA has the advantage of much stringent power control requirement. The timeslot structure also supports mobile assisted or mobile controlled handoff (MAHO). Frequency hopping (FH) is one of the most valuable features of TDMA systems [4]. There are two capacity increasing effects from FH [6]. The first is frequency diversity and the other is interference averaging. This is impossible for CDMA systems. According to [4], the 13 kbps speech coder in GSM is of better speech quality than 8.6kbps for IS-95 system.

2.3 Main Features of CDMA Systems

CDMA is a type of Spread Spectrum Multiple Access. In CDMA, narrowband message signal is multiplied by a very large bandwidth signal called the spreading signal. Spreading signal is a Pseudo-code sequence that has a chip rate, which is an order of magnitude greater than the data rate of the message [1]. All users use the same carrier frequency and may transmit simultaneously. Each user has its own pseudo random codeword, which is approximately orthogonal to all other code words, and all undesired code words will appear as noise. Fig. 3 [1] illustrates this.

Power control in CDMA is essential. Otherwise some users will jam the others. Power control ensures that each mobile within the base station coverage provides the same signal level to the base station. This is done by rapidly sampling the radio signal strength indicator (RSSI) levels of each mobile and then sending a power change command over the forward link. A tradeoff must be made if a mobile signal arrives at the cell site with a signal that is too weak, the weak signal will probably be dropped. If the power from a mobile user is large,
the performance of this mobile unit will be acceptable, but it will add undesired interference to with all other user in the cell. This is so-called near-far effect.

2.4 Advantages of CDMA Systems

It is bandwidth limited for TDMA systems, while it is interference limited for CDMA, which make CDMA uniquely suitable for interference dominated mobile radio environment [5]. Unlike TDMA, CDMA has a soft capacity limit, increasing the number of user in a CDMA system raise the floor noise floor in a linear-manner. Thus, there is no absolute limit in the number of user. However, the performance will reduce as capacity increases [1]. Multi-path fading may also be substantially decreases as the signal is spread over a large spectrum. The inherent frequency diversity will reduce the effects of small-scale fading, if the spread spectrum bandwidth is greater than the coherence bandwidth. Thus, addition equalization hardware is not required for CDMA system [1], [6]. Soft handoff which the MSC may chose the best version of the signal at any time without switching frequencies, is quite easily achieved with CDMA. Frequency and timeslot assignment and management entail a certain complexity in TDMA systems, which are not found in CDMA systems [6]. Another main advantage of CDMA is that coherent multiple transmission and reception (CMT) can be realized [7]. In CMT, the base stations surrounding a mobile station simultaneously transmit to the mobile station. Coherent multiple reception (CMR) in the downlink is obtained by coherently combine all signals arriving at the mobile station. Similarly, in the uplink, signal transmitted by the mobile station is simultaneously received by several base stations and are coherently combined to obtain the message. CMT and CMR are used to improve the exploitation of the transmitted power and therefore reduce the necessary transmitted power and the electromagnetic load in the air. With CMT there is also a reduction of the carrier-to-interference ratio C/I by approximately \( k \) dB (depending on the number of base station transmitting and receive by the mobile station) due to the diminution of the transmission power in the \( k \) base stations by a factor \( k \). In CDMA, only a correlator, which is simpler than an equalizer, is needed [11]; however this is at the expense of slower transmission rate.

3. SPECTRUM EFFICIENCY

It is essential to utilize the limited frequency spectrum effectively [3]. Spectrum efficiency for most mobile radio system is simply the channel efficiency, i.e., the maximum number of channels in a given frequency band. However, for cellular systems, the reuse of frequencies must also be considered. Spectrum efficiency is directly related to system capacity. A simple calculation is shown to compare system capacity of TDMA and CDMA system.

3.1 Computation of Radio Capacity

The cellular radio capacity, \( m \), of TDMA can be determined by the relationship [5],

\[
m = \frac{B_t}{B_c} \frac{1}{K} - (1)
\]

where \( B_t \) is the total allocated spectrum for the system, \( B_c \) is the channel bandwidth, and \( K \) is the number of cells in a frequency reuse pattern and can be obtained by,

\[
K = q^2/3 - (2)
\]

where \( q \) is the co-channel interference reduction factor (CIRF).

In mobile radio environment, we may assume a fourth power rule, i.e. \( \gamma = 4 \),

\[
m = \frac{B_t}{E_b N_0 (2/3) C/I)} = \frac{M}{K} \text{ Number of channels/cell} - (3)
\]

Where \( M \) is the total number of equivalent channels and \( (C/I) \) is the minimum received carrier-to-interference ratio per channel or per time slot.

The C/I ratio of CDMA and TDMA system is related to \( E_b/N_0 \) through (4)

\[
\frac{C}{I} = \frac{E_b}{N_0} - R_0 \frac{E_b}{E_t} - (4)
\]

where \( R_0 \) is the transmission data rate, \( B_c \) is the transmission bandwidth, \( E_b \) is the energy per bit and \( N_0 \) is the interference power per hertz.
For TDMA capacity calculation, $R_c = B$, since TDMA use designated time slots, hence C/I is always positive as baseband $E_b/N_o$ is always greater than one. However, for CDMA the transmission bandwidth, which is also the spread-bandwidth is $B_i >> R_c$, and hence C/I is always negative. This is because all the channels share the same bandwidth resulting in the remaining M-1 users appearing as interference to each user.

Power control can increase the capacity of CDMA systems [1], [5]. With forward link power control, the C/I of a mobile unit at a distance $R$ at the cell boundary can be derived [5] as

$$C/I = 1/1.656M - (5)$$

With reverse link power control, interference power for any received signal from the mobile is $(M-1)$ times the desired signal power as the remaining $(M-1)$ mobiles act as interferes.

$$C/I = 1/(M-1) - (6)$$

Allotted total spread bandwidth is normally $B_i = 1.25$ MHz. This is ten percent of total spectral allocation, which is 12.5 MHz for cellular telephone service. A bit rate of 8kb/s is assumed as an acceptable toll quality vocoded speech. Typical values of $E_b/N_o = 6.5$dB and 8.5dB for CDMA [4]. The radio capacities are computed for both TDMA and CDMA Systems as follows.

### 3.2 Capacity for CDMA with Power Control

The C/I required for $E_b/N_o = 8.5$ and 6.5dB can be computed using equation (4) with $B_i = 1.25$MHz

For CDMA system $q = D / R = 2$ and hence $k = q^2 / 3 = 1.33$ [5].

**Forward Link:**

Using (5),

$$M = 13.41 \text{ for } C/I = 0.045 \text{ (-13.4dB)}$$

$$M = 21.56 \text{ for } C/I = 0.028 \text{ (-15.4dB)}$$

The radio capacity using (3), then becomes,

$m = 10.08 \text{ channels/cell for } C/I = 0.045 \text{ (-13.4dB)}$

$m = 22.70 \text{ channels/cell for } C/I = 0.028 \text{ (-15.4dB)}$

**Reversed Link:**

Using (6),

$$M = 23.22 \text{ for } C/I = 0.045 \text{ (-13.4dB)}$$

$$M = 36.71 \text{ for } C/I = 0.028 \text{ (-15.4dB)}$$

The radio capacity then becomes,

$m = 17.46 \text{ channels/cell for } C/I = 0.045 \text{ (-13.4dB)}$

$m = 27.60 \text{ channels/cell for } C/I = 0.028 \text{ (-15.4dB)}$

Hence from the above calculations, with power control, the mobile capacity is forward link limited. Therefore the capacity of 10.08 channels/cell is chosen. Unlike TDMA systems, which are bandwidth limited, the capacity of CDMA system is interference limited. Therefore, in CDMA system, the capacity increases as link performance for each user decrease as shown.

A way to reduce interference in CDMA system is to use directional antennas that receive signals from only a fraction of current users, thus reducing of interference. Another way is taking advantage of the intermittent nature of speech, which has a duty cycle of 3/8 [1], to operate in discontinuous transmission mode (DTX). In DTX mode, the transmitter is turned off during the periods of silence in speech. Thus, the average capacity of a CDMA system can be increased by a factor inversely proportional to the duty factor, which is approximately 2.6.

Hence, taking sectorization factor of 3 (i.e. 3 sectors of 120°) and voice activation of 2.6, the effective radio capacity of CDMA is:

$$m = 10.08 \times 2.6 \times 3 = 78.62 \text{ channels/cell}$$

### 3.3 Capacity for TDMA (GSM)

Assuming system parameters $B_i = 1.25$MHz, $B_c = 200$kHz and $R_b = 8$kb/s. GSM employs 8 time slots in 200kHz channel.

$$M = B_i / B_c = 1.25M/(200k/8) = 50 \text{ channels}$$

$$K = 3$$

$$m = M / K = 50/3 = 16.7 \text{ channels/cell}$$

### 3.4 Capacity for TDMA (IS-136)

Interim Standard 136 uses three time slotted users for each 30KHZ channel.

$$M = B_i / B_c = 1.25M/(30k/3) = 125 \text{ channels}$$

$$K = 4$$

$$m = M / K = 50/4 = 31.5 \text{ channels/cell}$$
From the above calculations, it can be seen that the capacity of CDMA about 4 times greater than GSM system and about 2.2 times greater than IS-136. Thus, CDMA has higher spectrum efficiency. This can be further explained by the fact that while TDMA reuse frequencies depending on the isolation between cells provided by the path loss in terrestrial radio propagation, CDMA can reuse the entire spectrum for all cells, this results in an increase of capacity by a large percentage over the normal frequency reuse factor [1]. However conditions such as non-ideal orthogonal of CDMA Pseudo-Code sequence and techniques such as Adaptive Channel Allocation (ACA) in addition of frequency hopping (FH) that can increase TDMA capacity is not included in the calculations.

4. THIRD GENERATION (3G) CELLULAR SYSTEMS

The worldwide success of 2nd generation cellular systems is much greater than what most people expected. However, these 2G systems are limited in data rate. Japan is the first to rollout with a detailed standardization of wideband code-division multiple access (W-CDMA) system. This process accelerates the standardization in Europe and US. Third generations become a reality as the regional standards bodies finalize their air interface proposals for International Mobile Telecommunications in the year 2000. There are several objectives [8] for the third generation systems: high spectrum efficiency, small low cost terminals, a global standard with a high degree of commonality, seamless roaming, provision of services for mobile and fixed users and also to allow users to use multiple services simultaneously. The minimum performance capabilities for user data rate specified by IMT-2000 in four different test-operating environments are as follows [9]:

- Vehicular environment: 144 kb/s
- Pedestrian environment: 384 kb/s
- Indoor office environment: 2.048 Mb/s
- Satellite environment: 9.6 kb/s

Besides 3G activities, IS-95, GSM and IS-136 continue evolving toward IMT-2000 requirements. 2.5G systems are developed to allow hard and software modifications to support higher data rates. There are three different paths for TDMA evolution. These include:(a) High Speed Circuit Switched Data (HSCSD); (b) General Packet Radio Service (GPRS); (c) Enhanced Data Rates for GSM Evolution (EDGE). GPRS and EDGE also supports IS-136. CDMA’s interim data solution is IS-95B and like GPRS, IS-95B is already being deployed worldwide, and provides high-speed packet and circuit switched data access in common CDMA radio channel. The eventual 3G evolutions for CDMA systems from IS-95 lead to cdma2000 based on the fundamental of IS-95 and IS-95B technologies. The eventual 3G evolutions for GSM, IS-136 systems lead to Wideband CDMA (W-CDMA). W-CDMA is based on the fundamentals of GSM, as well as the merged version of GSM and IS-136 through EDGE. This is discussed in [1, 8, 9, 10]

5. CONCLUSION

Systems based on TDMA and CDMA have been discussed. Both systems have their own advantages and disadvantages. Although, matured TDMA technologies have made it seem the obvious choice. Merits of CDMA such as higher capacity through voice activation and antenna soft handoff etc cannot be discarded and provide an edge for CDMA systems. Research and implementation of 3G systems is ongoing. With many enhancement from the present 2G systems, 3G will no doubt be as if not more successful.

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REFERENCE