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# Channel Spectral Efficiencies of Digital Cellular Standards

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***Abstract*-In this paper, spectral efficiencies of three digital cellular standards is illustrated. Spectral efficiencies refer to the information rate that can be transmitted over a bandwidth in a specific communication system. Spectral efficiencies of three digital cellular standard, The European TDMA digital cellular standard (GSM) , The North American digital cellular standard ( IS 54) , and The Japanese digital cellular standard (PDC).**

***Key Words:* TDMA (Time division multiple access), GMSK (Gaussian minimum phase shift keying), DQPSK(Demodulation Quadrature Phase Shift Keying),PDC (Pacific digital cellular).**

## I. INTRODUCTION

In 1991, the first US digital cellular (USDC) system hardware was installed in major US cities. The USDC standard IS 54 allowed cellular operators to replace gracefully some single user analog channels with digital channels which support three users in the same 30 KHz bandwidth with 824-894 MHz frequency band. The first generation European cellular systems are generally incompatible systems are now being replaced by the Pan European digital cellular standard GSM which was first deployed in 1990 in a new 900 MHz band which all of dedicated for cellular telephone service, the GSM standard has gained worldwide acceptance as the first universal digital cellular system with modern network features extended to each mobile user, and is the leading digital air interface for PCS service above 1800 MHz throughout the world. In Japan, the PDC standard digital cellular coverage using a system similar to North America's USDC.The PDC standard was developed in 1991 to provide for needed capacity in congested cellular bands in Japan. PDC is somewhat similar to the IS 54 standard, but uses 4-ary modulation for voice and control channels, making it more like IS 136 in North America. Frequency division duplexing and TDMA are used to provide three time slot for three users in a 20 ms frame on a 25 KHz radio channel. On each channel, π/4 DQPSK is used, with a channel data rate of 42 Kbps. Channel coding is provided using a rate 9/17 , K=5 convulational code with CRC. Speech coding is provided with a 6.7 kbps VSELP speech coder. An additional 4.5 kbps is provided by the channel coding, thereby proving 11.2 kbps of combined speech and channel coding per user.

A new half rate speech and channel coding standard will support six users per 20 ms frame. PDC is allocated 80 MHz in Japan. The low PDC band uses 130 MHz forward/reverse channel splits. The forward band uses 940 MHz to 956 MHz and the reverse band 810 MHz to 826 MHz the high PDC band use 48 MHz channel splits and operates in 1477 MHz to 1501 MHz for the forward link and 1429 MHz to 1453 MHz for the reverse link. PDC uses mobile assisted handoff and is able to support four- cell reuse.The comparisons between three digital cellular standards are shown in Table 1.

Table 1: Digital cellular Standards

| **Standard** | **Year** | **Multiple Access** | **Frequency Band** | **Modulation** | **Channel Bandwidth** |
|---|---|---|---|---|---|
| USDC | 1991 | TDMA | 824-894MHz | π/4 DQPSK | 30 KHz |
| GSM | 1990 | TDMA | 890-960 MHz | GMSK | 200 KHz |
| PDC | 1993 | TDMA | 810-1501 MHz | π/4 DQPSK | 25 KHz |

## II. 2G CELLULAR NETWORKS

Most of today's ubiquitous cellular networks use what is commonly called second generation 2G technologies which conform to the second generation cellular standard. Unlike the first generation cellular systems that relied exclusively on FDMA/FDD and analog FM, second generation standards use digital modulation formats and TDMA/FDD and CDMA/FDD multiple access techniques. The most popular 2G standards include three TDMA standards and one CDMA standard: (a) GSM, (b) USDC, (c) PDC. Today, many wireless service providers use both 1G and 2G equipment in major markets and often provide customers with subscriber units that can support multiple frequency bands and multiple air interface standards .Figure 1 illustrates how the world subscriber base was divided between the major 1G and 2G technologies. Table 2 highlights the technical specifications of the dominant GSM, IS 54 and PDC second generation standards.

Table 2: Key specifications of leading 2G technologies

| | **GSM** | **IS 54** | **PDC** |
|---|---|---|---|
| Uplink frequencies | 890-915 MHz | 824-894 MHz | 800-1500 MHz |
| Downlink Frequencies | 935-960 MHz | 869-894 MHz | 800-1500 MHz |
| Duplexing | FDD | FDD | FDD |

| | | | |
|---|---|---|---|
| Multiple Access | TDMA | TDMA | TDMA |
| Modulation | GMSK | π/4 DQPSK | π/4 DQPSK |
| Carrier separation | 200 Khz | 20 Khz | 25 Khz |
| Channel data rate | 270.833 kbps | 1.2288 mchips/s | 42 kbps |
| Voice channel per carrier | 8 | 3 | 3 |

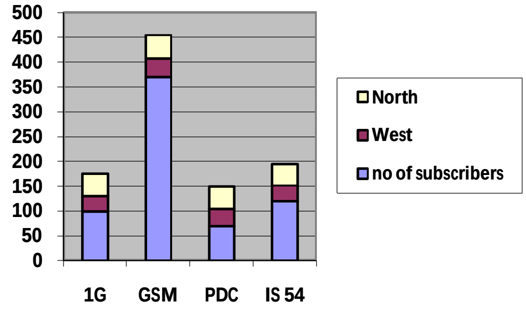

Fig.1: Worldwide subscriber base as a function of cellular technology in 2001.

### A. *Duplexing*

In wireless communication systems, it is often desirable to allow the subscriber to send simultaneously information to the base station while receiving information from the base station. Duplexing may be done using frequency or time domain techniques. Frequency division duplexing provides two distinct bands of frequencies for every user. The forward band provides traffic from the base station to the mobile, and the reverse band provides traffic from the mobile to the base station. In FDD any duplex channel actually consists of two simplex channels, and a device called duplexer is used inside each subscriber unit and base station to allow simultaneous bidirectional radio transmission and reception for both the subscriber unit and the base station on the duplex channel pair. The frequency separation between each forward and reverse channel is constant throughput the system, regardless of the particular channel being used.

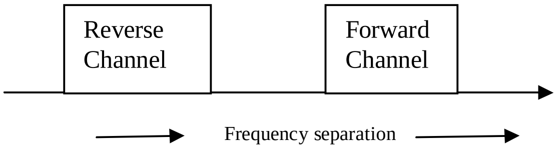

Fig 2: FDD provides two simplex channels at same time

### B. *Multiple Access*

FDMA, TDMA, and CDMA are the three major access techniques used to share the available bandwidth in a wireless communication system. These techniques can be grouped as narrowband and wideband systems, depending upon how the available bandwidth is allocated to the users. The duplexing technique of a multiple access scheme, as: Narrowband Systems: The term narrowband is used to relate the bandwidth of a single channel to the expected coherence bandwidth of the channel. In a narrowband multiple access system, the available radio spectrum is divided into a large number of narrowband channels. The channels are usually operated using FDD.

Wideband Systems: In wideband systems, the transmission bandwidth of a single channel is much larger than the coherence bandwidth of the channel. Thus, multipath fading does not greatly vary the received signal power within a wideband channel, and frequency selective fades occur in only a small fraction of the signal bandwidth at any instance of time.

All of the three North American, European and Japanese standard used TDMA access technique as shown in above tables.

TDMA systems divide the radio spectrum into time slots, and in each slot only one user is allowed to either transmit or receive. In TDMA/FDD systems, an identical or similar frame structure would be used solely for either forward or reverse transmission, but the carrier frequencies would be different for the forward and reverse links. In general TDMA/FDD systems intentionally induce several time slots of delay between the forward and reverse time slots for a particular user, so that duplexers are not required in the subscriber unit.

*Efficiency of TDMA:* The efficiency of a TDMA system is a measure of the percentage of transmitted data that contends information as opposed to providing overhead for the access scheme. The frame efficiency, $\eta_f$ ,is the percentage of bits per frame which contain transmitted data. Note that the transmitted data may include source and channel coding bits, so the raw end user efficiency of a system is generally less than$\eta_f$. The frame efficiency can be found as follows:

The number of overhead bits per frame is

$$boh = Nrbr + Ntbg + Nrbg \qquad (1)$$

Where $N_r$ is the number of reference bursts per frame, $N_t$ is the number of traffic bursts per frame, $b_r$ is the number of overhead bits per reference burst, $b_p$ is the number of overhead bits per preamble in each slot, and $b_g$ is the number of equivalent bits in each guard time interval.

$$bt = TfR(2)$$

where$T_f$is the frame duration,. And R is the channel bit rate. The frame efficiency$\eta_f$is thus given as

$$\eta f = \left(1 - \frac{boh}{bt}\right) * 100\%(3)$$

*Number of channels in TDMA system:*The number of TDMA channel slots that can be provided in a TDMA system is found by multiplying the number of TDMA slots per channel by the number of channels available and is given by

$N = \frac{m(Btot-2Bguard)}{Bc}$(4)

Where m is the maximum number of TDMA users supported on each radio channel. Note that two guard bands, one at the low end of allocated frequency band and one at the high end, are required to ensure that users at the edge of the band.

### *C.Modulation*

As shown in table 1 and 2 that two of the digital cellular standard i.e. IS 54 and PDC uses π/4 DQPSK modulation and GSM is based on GMSK.

#### *π/4 DQPSK Modulation*

The π/4 shifted QPSK modulation is a quadrature phase shift keying technique which offers a compromise between OQPSK and QPSK in terms of the allowed maximum phase transitions. It may be demodulated in a coherent or noncoherent fashion. In π/4 QPSK ,the maximum phase change is limited to +-135 degree , as compared to 180 degree for QPSK and 90 degree for OQPSK. Hence, the band limited π/4 QPSK signal preserves the constant envelope property better than band limited QPSK, but is more susceptible to envelope variations than OQPSK. An extremely attractive feature of this modulation is that it can be noncoherently detected, which generally simplifies receiver design. Further, it has been found that in the presence of multipath spread and fading, π/4 QPSK performs better than OQPSK. Very often, π/4 QPSK signals are differentially encoded to facilitate easier implementation of differential detection or coherent demodulation with phase ambiguity in the recovered carrier. When differentially encoded, π/4 QPSK is called π/4 DQPSK.

#### *GMSK:*

GMSK is a simple binary modulation scheme which may be viewed as a derivative of MSK. In GMSK, the side lobe levels of the spectrum are further reduced by passing the modulating NRZ data waveform through a premodulation Gaussian pulse shaping filter. Baseband Gaussian pulse shaping smoothes the phase trajectory of the MSK signal and hence stabilizes the instantaneous frequency variations over time. This has the effect of considerably reducing the side lobe levels in the transmitted spectrum.Premodulation Gaussian filtering converts the full response message signal (where each baseband symbol occupies a single bit period T) into a partial response scheme where each transmitted symbol spans several bit periods. However, since pulse shaping does not because the pattern averaged phase trajectory to deviate from that of simple MSK, GMSK can be coherently detected just as an MSK signal, or noncoherently detected as simple FSK. In practice, GMSK is most attractive for its excellent power efficiency and its excellent spectral efficiency. The premodulation Gaussian filtering introduces ISI in the transmitted signal, but it can be shown that the degradation is not severe if the 3 dB bandwidth bit duration product(BT) of the filter is greater than 0.5 GMSK sacrifices the irreducible error rate caused by partial response signaling in exchange for extremely good spectral efficiency and constant envelope properties.

The GMSK premodulation filter has an impulse response is given by

$hG(t) = \exp\left(\frac{\pi 2}{\alpha 2t2}\right)$ (5)

and the transfer function given by

$$HG(f) = \exp(-\alpha 2f2) \qquad (6)$$

The parameter α is related to B, the 3 dB baseband bandwidth of $H_G(f)$ , by

$$\alpha = \frac{\sqrt{1n2}}{\sqrt{2B}} = 0.5887/B \qquad (7)$$

And the GMSK may be completely defined from B and the baseband symbol duration T. It is therefore customary to define GMSK by its BT product.

## III. SPECTRAL EFFICIENCIES

The link spectral efficiency of a digital communication system is measured in bits/Hz or, less frequently but unambiguously, in (bit/s)/Hz. It is the net bit rate (useful information rate excluding error-correcting codes) or maximum throughput divided by the bandwidth in hertz of a communication channel or a data link. Alternatively, the spectral efficiency may be measured in bit/symbol, which is equivalent to bits per channel use (bpcu), implying that the net bit rate is divided by the symbol rate (modulation rate) or line code pulse rate.Link spectral efficiency is typically used to analyze the efficiency of a digital modulation method or line code, sometimes in combination with a forward error correction (FEC) code and other physical layer overhead. In the latter case, a "bit" refers to a user data bit; FEC overhead is always excluded.The modulation efficiency in bit/s is the gross bit rate (including any error-correcting code) divided by the bandwidth.

Example 1: A transmission technique using one kilohertz of bandwidth to transmit 1,000 bits per second has a modulation efficiency of 1 (bit/s)/Hz.If the SNR is 1 times expressed as a ratio, corresponding to 0 decibel, the link spectral efficiency cannot exceed 1 (bit/s)/Hz for error-free detection (assuming an ideal error-correcting code) according to Shannon-Hartley regardless of the modulation and coding.

Note that the good put (the amount of application layer useful information) is normally lower than the maximum throughput used in the above calculations, because of packet retransmissions, higher protocol layer overhead, flow control, congestion avoidance, etc. On the other hand, a data compression scheme, such as the V.44 or V.42bis compression used in telephone modems, may however give higher good put if the transferred data is not already efficiently compressed.

The link spectral efficiency of a wireless telephony link may also be expressed as the maximum number of simultaneous calls over 1 MHz frequency spectrum in Erlangs per megahertz, or E/MHz This measure is also affected by the source coding (data compression) scheme. It may be applied to analog as well as digital transmission.

In wireless networks, the link spectral efficiency can be somewhat misleading, as larger values are not necessarily more efficient in their overall use of radio spectrum. In a wireless network, high link spectral efficiency may result in high sensitivity to co-channel interference (crosstalk), which affects the capacity. For example, in a cellular telephone network with frequency reuse, spectrum spreading and forward error correction reduce the spectral efficiency in (bit/s)/Hz but substantially lower the required signal-to-noiseratio in comparison to non-spread spectrum techniques. This can allow for much denser geographical frequency reuse that compensates for the lower link spectral efficiency, resulting in approximately the same capacity (the same number of simultaneous phone calls) over the same bandwidth, using the same number of base station transmitters. As discussed below, a more relevant measure for wireless networks would be system spectral efficiency in bit/s/Hz per unit area. However, in closed communication links such as telephone lines and cable TV networks, and in noise-limited wireless communication system where co-channel interference is not a factor, the largest link spectral efficiency that can be supported by the available SNR is generally used.The system spectral efficiency of a cellular network may also be expressed as the maximum number of simultaneous phone calls per area unit over 1 MHz frequency spectrum in *E/MHz* per cell,E/MHz persector, E/MHz per site, or (E/MHz)/m$^2$. This measure is also affected by the source coding (data compression) scheme. It may be used in analog cellular networks as well.

*Spectral Efficiency of USDC IS 54:*

If the SNR of a wireless communication link is 20 dB and the RF bandwidth is 20 kHz, determine the maximum theoretical data rate to the USDC illustrated above.
As S/N is 20 dB is equals to 100 and the Radio frequency bandwidth (B) is 20000Hz
As discussed earlier by using Shannon’s channel capacity formula, the maximum possible data rate

$$C = Blog2(1 + \frac{S}{N})$$

$$20000log2(1 + 100) = 133.164kbp$$

Theoretically, the data rate is 48.6kbps which is only one fourth under 20 dB SNR conditions.

*Spectral Efficiency of GSM:*

If the SNR of a wireless communication link is 10 dB , 30 dB and the radio frequency and maximum data rate that can be supported in a 200 kHz channel . How this does differs from theoretical data rate for GSM digital cellular standard.
So, for SNR = 10 dB = 10, B = 200 KHz
By using formula

$C = Blog2\left(1 + \frac{S}{N}\right)$
$= 200000log2(1 + 10)$
$= 200000log10(11)/log10(2)$
$= 200000 * 3.459$
$= 691.886kbps$

The GSM data rate is 270.883 kbps, which is only about 40%.

If the SNR is 30 dB
Therefore = 1000
And B = 200 KHz

The maximum possible data rate is

$C = Blog2\left(1 + \frac{S}{N}\right)$
$= 200000\ log2(1 + 1000)$
$.= 1.99Mbps$

*Spectral Efficiency of PDC:*

If the SNR of a wireless communication link is 30 dB and the radio frequency and maximum data rate that can be supported in a 30 kHzchannel. How this does differs from theoretical data rate for PDC digital cellular standard.
So, for SNR = 30 dB = 10, B = 30 KHz
By using formula

$C = Blog2\left(1 + \frac{S}{N}\right)$
$= 30000log2(1 + 1000)$
$= 299.016kbps$

In the W-CDMA 3G cellular system, every phone call is compressed to a maximum of 8,500 bit/s (the useful bit rate), and spread out over a 5 MHz wide frequency channel. This corresponds to a link throughput of only 8,500/5,000,000 = 0.0017 (bit/s)/Hz. Let us assume that 100 simultaneous (non-silent) calls are possible in the same cell. Spread spectrum makes it possible to have as low a frequency reuse factor as 1, if each base station is divided into 3 cells by means of 3 directional sector antennas. This corresponds to a system spectrum efficiency of over 1 × 100 × 0.0017 = 0.17 *(*bit/s)/Hz per site, and 0.17/3 = 0.06 (bit/s)/Hz per cell orsector.

GSM provides fully utilized 900 MHzfrequency band with 200 KHz carrierspacing whereas carrier spacing of IS-136 and PDC are 30 KHz and 25 KHz. Thechannels per carrier of GSM is 8 full rate whereas for IS-136 and PDC is 3 full rate.All the three standard support short message services (SMS). These standards used User/Terminal authentication for fraud control and provides fullInternational roaming capability.GSM and IS-136 supports an emergency service, where the nearest emergency service provider is notified by dialing three digits similar to 911. It is also found that IS-136 has the ability to quickly roll out advanced services to meet future consumer’s needs. It share the same 21 analogue call set up channels with AMPS so that the call processing is the same between the two systems and handsets can support dual AMPS/D-AMPS. The IS-136 system adds new power class of mobile phone to allow
reduces the minimum cell site radius. It is also found that a compact portable phone is one of the most special features of PDC. A key feature of PDC is mobile assisted hand off which facilitates the use of small cells for efficient frequency usage. It is gaining popularity due to high quality, high security, and a longer handset battery life. It has given

the most spectrally of TDMA technology to the user. It also has prepaid calling, personal number, Universal access numbers, advanced charging scheme and wireless virtual private networks.

Comparison between all the three digital cellular standards are based on different parameters as discussed above bit rate, data rate ,RF frequency, throughput , type of access technique, modulation scheme and carrier separation , and maximum data rate of USDC and GSM under 20 dB SNR is almost 40% of the theoretical values as shown in above examples.

Table 3: Spectral Efficiency of digital cellular standard under theoretical values

| Service | Standard | Year | Max net bit rate R | B/WB | Max spectral Efficiency R/B |
|---|---|---|---|---|---|
| 1G | Cellular | 1983 | 0.0003 | 0.030 | 0.01 |
| GSM | Cellular | 1991 | 270.833 | 200 khz | 0.0013 |
| PDC | Cellular | 1993 | 48.6 | 30 khz | 0.00162 |

***Note*:**

The spectral efficiency can be improved by radio resource management techniques such as efficient fixed or dynamic channel allocation, power control, link adaptation and diversity schemes.

## IV. CONCLUSION

In this paper anoverview of mobile communication and the standards of digital cellular especially for GSM: The European TDMA digital cellular standard, IS-136: TDMA based digital cellular system in United States and PDC: The Japanese TDMA based digital cellular system based on service aspects. From the above discussion, it has been cleared that the three digital cellular systems have their own special features and form their achievement during short periods. It is also expected that the three standards will serve comfortably the demands of the customers.

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