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Performance Analysis of 4G (OFDMA), 3G,2G and 1G cellular systems

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Abstract—Spectral efficiency is a key factor in the design of cellular communication systems as it quantifies how well the limited frequency spectrum resource is utilized. The efficient use of spectrum is analyzed in terms of coverage area, capacity and reuse distance. In this paper the Spectral efficiency of various generations of cellular communication systems starting from 1G to 4G based on air-interface techniques (FDMA, TDMA, CDMA, WCDMA and OFDMA) is estimated in the units of Erlangs/MHz/m2. The variation of Spectral efficiency is studied with the area of coverage and frequency reuse distance.

Keywords—Radio capacity, Spectral efficiency, FDMA, TDMA, CDMA, WCDMA, OFDMA

Introduction

To allow many users to share simultaneously a finite amount of radio spectrum, various methods have been developed and the goal behind these methods is to handle as many calls as possible in a given bandwidth with least possible degradation in the performance of the system. This concept is called as multiple access. There are several ways to access the channel. The basic possible access methods are: Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), and Wideband Code Division Multiple Access (WCDMA), and Orthogonal FrequencyDivision Multiple Access (OFDMA).

FDMA and TDMA are 1G and 2G cellular systems. In 3G systems, CDMA is used and in 4G, OFDMA technique is used. Recently, Wideband Code Division Multiple Access (WCDMA) is being used in 3G systems because it uses a wide bandwidth (5MHz) and provides more services [1]. The received Walsh codes are orthogonal in the downlink transmission of WCDMA. This orthogonality property is lost in multipath propagation which results in inter-user and/or inter-symbol interference (ISI). To mitigate this problem, a new multiple access technique Orthogonal Frequency Division Multiple Access (OFDMA) is proposed and implemented for the LTE-downlink communication (4G). The advantages of OFDMA system are high data rate, operates in a multipath radio environment and efficient sharing of limited resources.

The performance of this multiple access technique is mainly depends on two factors which are radio capacity [2] and spectral efficiency. Spectral efficiency depends on the number of users in the cell (Radio capacity). First the Radio capacity of the multiple access technique is measured and from this Radio capacity values the spectral efficiency of the multiple access technique is estimated.

Radio Capacity of Cellular Systems

The radio capacity is defined as the maximum number of users that can be supported simultaneously in each cell. The radio capacity in general quantified as the number of channels per cell. With different conditions, the radio capacity can be represented in different units [2].

- For a given blocking probability(Grade of service) Radio capacity represented in the units of Erlangs/cell
- For a given cell area in square miles the Radio capacity represented in the units of Erlangs/m^2 or Erlangs/km^2
- For a given average holding time per each call the Radio capacity represented in the units of number of calls/hour/mi^2
- For a given average calls per user in a busy hour, the Radio capacity represented in the units of number of users/mi^2
- For a given total area in a system (square miles) the Radio capacity represented in the units of number of users in a system
- The other representations of radio capacity such as number of calls/h/cell, number of users/ cell and number of users/channel in a busy hour

In this paper the Radio capacity is considered in the units of number of users per cell.

A. Radio capacity of FDMA and TDMA

The FDMA is used as a common air interface in 1G wireless system.

Radio capacity of FDMA is given by

$$C_{fdma} = \frac{B_{sys}}{B_c K} \tag{1}$$

Where B_{sys} is bandwidth of the system,
B_c is bandwidth of the carrier and
K is frequency reuse pattern.

TDMA is a digital technique [2] that divides a single channel or band into time slots. Each time slot is used to transmit one byte or another digital segment of each signal in the sequential serial data format. This technique works well with slow voice data signals, but it’s also useful for compressed video and other high-speed data. The TDMA is used as a common air interface in 2G wireless systems.

Radio capacity of TDMA is given by

$$C_{tdma} = \frac{B_{sys}}{B_c K} T \quad (2)$$

Where T is the number of time slots.

B. Radio capacity of CDMA system

CDMA is a spread spectrum scheme in which a number of users can occupy the entire transmission bandwidth at all the time. However, they are all assigned a unique code to differentiate them from each other [3].

The Radio capacity of CDMA system is

$$C_{cdma} = 1 + \frac{B_s / R_b}{E_b / N_0} - \frac{\eta}{P_r} \quad (3)$$

Where B_s is spreading bandwidth,
R_b is information bit rate,
E_b/N_0 is Energy per bit to Noise density ratio,
η is noise power spectral density and
p_r is power of the received signal from each user.

C. Radio capacity of WCDMA system

WCDMA (Wideband Code Division Multiple Access), is an air interface standard found in 3G mobile telecommunication networks which allow the mobile operators to deliver higher bandwidth applications including streaming and broadband Internet access [4].

Radio capacity of WCDMA is

$$C_{wcdma} = 1 + \frac{G_P . A_a}{E_b / N_0} . \frac{\alpha_{cf}}{(1 + I_{co})v} - \frac{\sigma^2}{P_r} \quad (4)$$

Where G_p is Process gain,
A_a is antenna gain ratio,
ν is voice activity factor
α_{cf} is power control correction factor,
I_{co} is Co-channel interference from other cells and
σ^2 / P_r is noise power to received power ratio.

D. Radio capacity of OFDMA system

Recently, in the 4th generation of mobile communications a new access like orthogonal frequency division multiple access (OFDMA), single carrier FDMA, Interleaved FDMA and multi carrier CDMA are introduced. OFDMA-based systems [6] allow efficient sharing of limited resources such as spectrum and transmit power between multiple users [5]. The advantages of these systems are able to deliver high data rate, and operate in the hostile multipath radio environment.

Radio capacity of OFDMA is

$$C_{ofdma} = \frac{K.N_S.L_e.B.L_{bh}}{R_b} \quad (5)$$

Where N_s is number of sectors,
K is over-subscribe factor,
B is bandwidth,
R_b is information bit rate,
L_e is link efficiency (bps/Hz) and
L_{bh} is busy hour load data rate.

For the LTE, OFDMA is used for the downlink and Single-carrier FDMA is used for the uplink. Then, the number of users for the downlink can be approximated as

$$N_{DL,ofdma} = \frac{(1 - P_{coh})\kappa.N_s.L_e.B.L_{bh}}{\nu.R_b.\gamma} \quad (6)$$

Where P_{coh} is percentage of channel overhead power,
γ is signal-to-noise ratio and
ν is voice activity factor.

Spectral Efficiency of Cellular Systems

Spectral efficiency is a measure of the quantity of users or services that can be simultaneously supported by a limited radio frequency bandwidth in a defined geographic area. It also be defined in the maximum aggregated throughput or good put, i.e. summed over all users in the system, divided by the channel bandwidth. This measure is affected not only by the single user transmission technique, but also by multiple access schemes and radio resource management techniques utilized. It can be substantially improved by dynamic radio resource management [6].

In digital cellular systems, the system spectral efficiency is typically measured in

- (bit/s)/Hz per unit area
- (bit/s)/Hz per cell or in (bit/s)/Hz per site

The system spectral efficiency of a cellular network (for both analog and digital cellular systems) 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 per sector
- E/MHz per site or (E/MHz)/m^2

A. Spectral efficiency of Cellular systems with respect to Area of cell

The system spectral efficiency of a cellular network expressed as

$$S = \frac{CL_o}{B_{sys} K A_c} \text{ Erlangs/MHz/m}^2 \quad (7)$$

Where C is Radio capacity, number of simultaneous users in the cell
B_{sys} is Total bandwidth of system
K is Cell reuse pattern
A_c is Total area per cell (m^2)
L_o is Offered traffic per cell (Erlangs/cell)

B. Spectral efficiency of Cellular systems with respect to reuse distance

Cell reuse factor is given by $q = \frac{D}{R\sqrt{3}}$

Where D is reuse distance
R is cell radius

Spectral efficiency in terms of reuse distance is given by

$$S = \frac{CL_o}{B_{sys}(D / R\sqrt{3}) A_c} \text{ Erlangs/MHz/m}^2 \quad (8)$$

Results and Discussions

In this section, the spectrum efficiency of different air interface techniques such as FDMA, TDMA, CDMA, WCDMA and OFDMA are evaluated with respect to cell area and reuse distance.

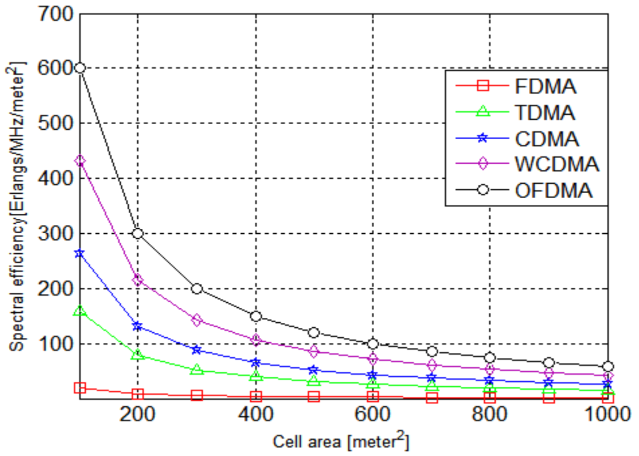

Fig.1.Variation of spectral efficiency with respect to cell area

Table 1. Variation of spectral efficiency with cell area

Reuse Distance [Km]	Spectral Efficiency [Erlangs/MHz/m^2]				
	FDMA	TDMA	CDMA	WCDMA	OFDMA
2	24.76	198.14	247.68	405.29	562.91
3	16.51	132.09	165.12	270.19	375.27
4	12.38	99.07	123.84	202.64	281.45
5	9.90	79.25	99.07	162.12	225.16
6	8.25	66.04	82.56	135.10	187.63
7	7.07	56.61	70.76	115.80	160.83
8	6.19	49.53	61.92	101.32	140.72
9	5.50	44.03	55.04	90.06	125.09
10	4.95	39.62	49.53	81.06	112.58

From the Fig.1 and Table 1, the spectral efficiency decreases from 20 to 2 Erlangs/MHz/m^2 in FDMA, from 160 to 16 Erlangs/MHz/m^2 in TDMA, from 264 to 26.4 Erlangs/MHz/m^2 in CDMA systems, from 432 to 43.2 Erlangs/MHz/m^2 in WCDMA and from 600 to 60 Erlangs/MHz/m^2 in OFDMA as the area of the cell increases from 100 m^2 to 1000 m^2.

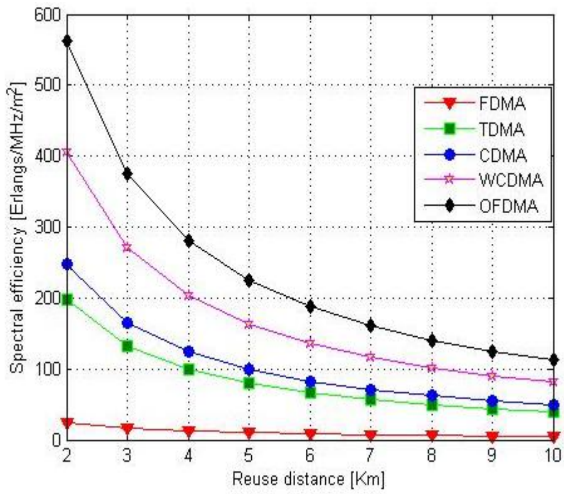

Fig.2.Variation of spectral efficiency with reuse distance

Table 2. Variation of spectral efficiency with reuse distance

Cell area [m^2]	Spectral Efficiency[Erlangs/MHz/m^2]				
	FDMA	TDMA	CDMA	WCDMA	OFDMA
100	20	160	264	432	600
200	10	80	132	216	300
300	6.6	53.3	88	144	200
400	5	40	66	108	150
500	4	32	52.8	86.4	120
600	3.3	26.6	44	72	100
700	2.8	22.8	37.7	61.7	85.7
800	2.5	20	33	54	75
900	2.1	17.7	29.3	48	66.6
1000	2	16	26.4	43.2	60

From the Fig.2 and Table 2, as the reuse distance increases from 2Km to 10 Km the spectrum efficiency decreases from 24.76 to 4.95 Erlangs/MHz/m^2 in FDMA, from 198.14 to 39.62 Erlangs/MHz/m^2 in TDMA, from 247.68 to 49.53 Erlangs/MHz/m^2 in CDMA systems, from 405.29 to 81.06 Erlangs/MHz/m^2 in WCDMA and from 562.91 to 112.58 Erlangs/MHz/m^2 in OFDMA.

Conclusions

In this paper the basic principles of various multiple access schemes, the mathematical representation and the concept of spectral efficiency is described. A simple evaluation method of spectral efficiency is proposed in judging different multiple access techniques. The proposed method is based on the evaluation of radio capacity. The spectral efficiency in Erlangs/MHz/m^2 is obtained for FDMA, TDMA and CDMA and OFDMA schemes in terms of area of the cell, frequency reuse distance.

From the results, it is observed that the Spectral efficiency of OFDMA is decreases with increase of cell area and frequency reuse distance. i.e., the small cellular areas and the small frequency reuse distance results greater spectrum efficiency.

The spectral efficiency of cellular OFDMA is also compared with the other multiple accesses techniques such as FDMA, TDMA, CDMA and WCDMA. From the results, it can be concluded that the Spectral efficiency of cellular OFDMA is more than the other multiple accesses techniques.

From the above demonstration the cellular OFDMA air-interface offers better spectral efficiency than other air-interface techniques. Therefore, the OFDMA can be selected as the multiple access schemes for the 4G cellular mobile communication systems.

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