Evaluation of Spectral Efficiency of Cellular OFDMA system compared with FDMA, TDMA, CDMA and WCDMA

[1]SK THAHERBASHA, [2]N DURGA RAO, [3]P BALAKRISHNA
Assistant Professor
ECE Department
Vignan's Nirula Institute of Technology & Science for Women
Guntur, India

Abstract : Spectral efficiency (SE) is a key factor in design of cellular communication system 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/m^2. The variation of Spectral efficiency is studied with area of coverage and frequency reuse distance.

***IndexTerms* - Radio capacity, Spectral efficiency, FDMA, TDMA, CDMA, WCDMA, OFDMA.**

I. 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 Wide band Code Division Multiple Access (WCDMA).Today's wireless technologies are operate with spectral efficiency and today's cellular architectures inherently deliver services to large number of people in an extremely efficient manner. As described in this paper, no stone is being left unturned in the quest to make wireless networks as efficient as possible.

The performance of this multiple access techniques is mainly depends on two factors which are radio capacity and spectral efficiency. Spectral efficiency is depends on the number of users in the cell (Radio capacity). First we calculate the Radio capacity of the multiple access technique, from this Radio capacity values we can calculate the spectral efficiency of the multiple access technique. In Section II, we estimated the radio capacities of FDMA, TDMA, CDMA, WCDMA and OFDMA. In Section III, we estimated the spectral efficiencies of FDMA, TDMA, CDMA, WCDMA and OFDMA. We present results in Section IV and conclude the paper in Section V.

II. RADIO CAPACITY IN 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 number of channels per cell. With different conditions, the radio capacity can be represented in different units [1].

- 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.

Radio capacity of FDMA and TDMA:

The FDMA is used as a common air interface in 1G wireless system [1] which are Analog Mobile Phone Systems (AMPS) and Total Access Communication Systems (TACS).

$$\text{Radio capacity} = C_{fdma} = \frac{B_{sys}}{B_c K} \qquad (1)$$

Where B_{sys}: Bandwidth of the system
B_c : Bandwidth of the carrier
K: frequency reuse pattern

TDMA is a digital technique [1] 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 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.

$$\text{Radio capacity} = C_{tdma} = \frac{B_{sys}}{B_c K} T \qquad (2)$$

Where T is the number of time slots

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 [2].

$$\text{The Radio capacity} = C_{cdma} = 1 + \frac{B_s / R_b}{E_b / N_0} - \frac{\eta}{P_r} \qquad (3)$$

Where

B_s: spreading bandwidth

R_b: information bit rate

E_b/N_0: Energy per bit to Noise density ratio

η: Noise power spectral density

p_r: Power of the received signal from each user

Radio capacity of WCDMA system:

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

Radio capacity of WCDMA:

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

Where

G_p: Process gain

A_a: Antenna gain ratio

v: Voice activity factor

α_{cf}: Power control correction factor

I_{co}: Co-channel interference from other cells

σ^2 / P_r: Noise power to received power ratio

Radio capacity of OFDMA system:

Recently, in 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 [5] are able to deliver high data rate, operate in the hostile multipath radio environment, and allow efficient sharing of limited resources such as spectrum and transmit power between multiple users [4].

Radio capacity of OFDMA:

$$C_{ofdma} = \frac{\kappa . N_s . L_e . B . L_{bh}}{R_b}$$

Where

N_s: Number sectors

κ: Over-subscribe factor

B: Bandwidth

R_b: Information bit rate

L_e: Link efficiency (bps/Hz)

L_{bh}: 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

$$N_{DL,ofdma} = \frac{(1 - P_{coh}) \kappa . N_s . L_e . B . L_{bh}}{v . R_b . \gamma} \quad (5)$$

Where

P_{coh} is percentage of channel overhead power,

γ is signal-to-noise ratio and

ν is voice activity factor

III. SPECTRAL EFFICIENCY IN 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 [5].

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

$$\text{Spectral efficiency} = S = \frac{CL_o}{B_{sys} K A_c} \text{ Erlangs/MHz/m}^2 \qquad (6)$$

Where

C: Radio capacity, number of simultaneous users in the cell

B_{sys}: Total bandwidth of system

K: Cell reuse pattern

A_c: Total area per cell (m^2)

L_o: Offered traffic per cell (Erlangs/cell)

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

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

D: reuse distance

R: cell radius

Spectral efficiency in terms of reuse distance is given by

$$S = \frac{CL_o}{B_{sys}(D/R\sqrt{3})A_c} \text{ Erlangs/MHz/m}^2 \qquad (7)$$

IV. RESULTS

In this section, numerical simulation of results to evaluate the spectrum efficiency of different air interface techniques such as FDMA, TDMA, CDMA, WCDMA and OFDMA. We estimate the number of users in a cell from equations (1) to (5). By using equation (6) we can estimate the spectral efficiency of multiple accesses with variation of coverage area. The coverage area is varied from 100 m^2 to 1000 m^2.

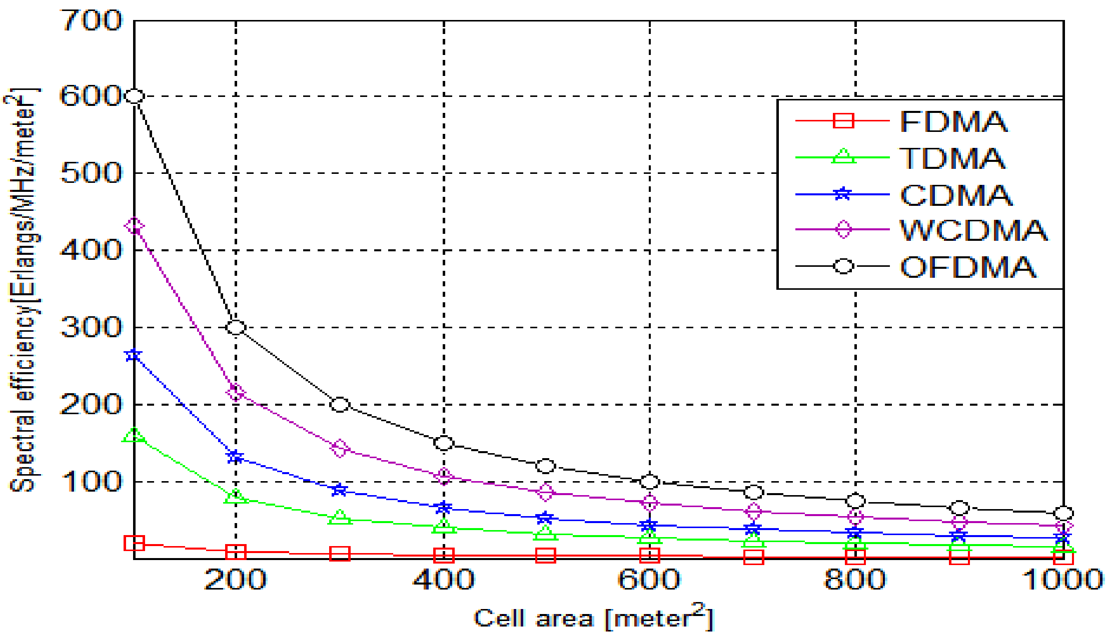

Fig.1.Variation of spectral efficiency with respect to cell area

Tabel 1. Variation of spectral efficiency with cell area

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 above result the spectral efficiency of cellular OFDMA is varied from 600 to 60 Erlangs/MHz/m^2 with variation of cell area from 100 to 1000 m^2. The Spectral efficiency of OFDMA is decreases with increase of cell area. The spectral efficiency of cellular OFDMA is also compared with the other multiple accesses techniques such as FDMA, TDMA, CDMA and WCDMA. The spectral efficiency of cellular OFDMA is more than the other multiple accesses techniques.

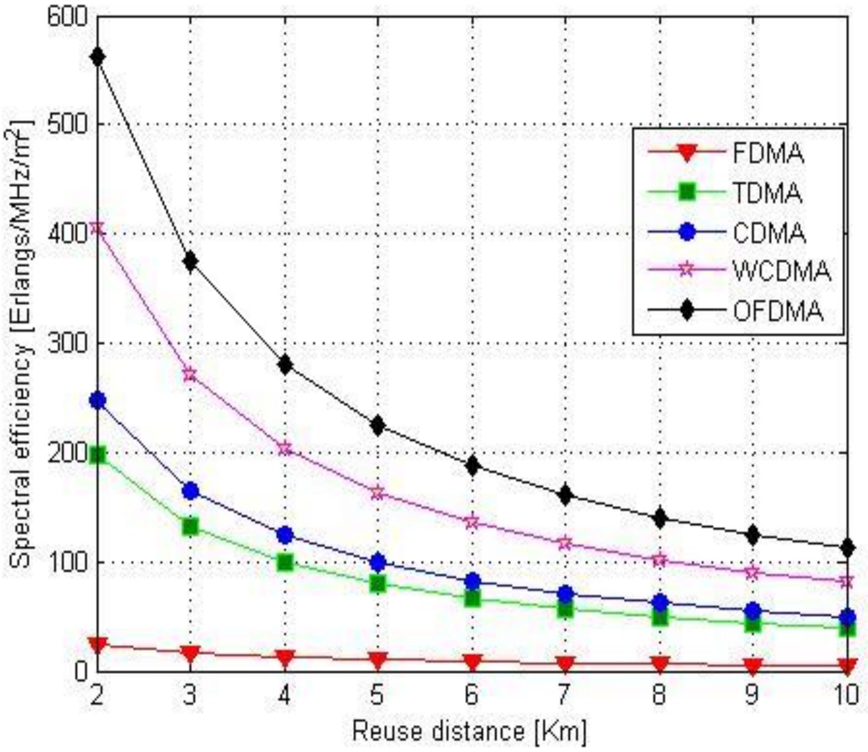

Fig.2.Variation of spectral efficiency with reuse distance

Tabel 2. Variation of spectral efficiency with reuse distance

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 above result the spectral efficiency of cellular OFDMA is varied from 562.9 to 112.5 Erlangs/MHz/m^2 with variation of frequency reuse distance from 2km to 10Km. The Spectral efficiency of OFDMA is decreases with increase of frequency reuse distance. The spectral efficiency of cellular OFDMA is also compared with the other multiple accesses techniques such as FDMA, TDMA, CDMA and WCDMA. The Spectral efficiency of cellular OFDMA is more than the other multiple accesses techniques

V. CONCLUSION

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 schemes in terms of area of the cell, frequency reuse distance.

As the area of the cell increases from 100 m^2 to 1000 m^2 the spectrum 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 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. It is observed that the small cellular areas and the small frequency reuse distance results greater spectrum efficiency.

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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