Network Gain Determination for Coverage Areas Covered by Single Frequency Networks

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Abstract: The aim of this paper is to investigate the advantages of single frequency network (SFN) to improve the radio coverage of the 4th generation mobile communication systems, which employ transmitter diversity. In comparison with the current transmitter network topologies, the diversity gain of SFN (often referred to as network gain of SFN) assists network planners to obtain uniform radio coverage with low power transmitters. This topology of transmitters mitigates the effect of shadow fading.

Index Terms: Mobile Communication, 4th G Mobile Systems, Single Frequency Networks, OFDM

I. Introduction

Provision of services to the mobile receivers is one of the key factors for success of a communication service. In fact, the main objective of the communication service planners is to communicate with anyone at anytime and anywhere. In this regard several generations for mobile communication systems have been devised.

Based on the analogue FM modulation, the first generation mobile communication systems started in 1980. National Mobile Telephone (NMT) and Advanced Mobile Phone Systems (AMPS) are the most familiar first generation systems [1-2].

With advances in digital techniques for communication systems, the second-generation mobile communication systems have been in use since 1990. Several standards, such as the Global System for Mobile (GSM) in UK, IS-54/136 and IS-95 in US and Japanese Personal Digital Cellular (PDC) have been developed [1-2].

Recently with the increase of Internet demands through the communication networks, provision of the Internet is necessary for the success of a communication system. The first and second generation systems were optimized for voice communication and they are not efficient for data communication.

Although several efforts have been made for improving the second generation for data communication [2], development of new generations for mobile communications systems for data and voice communication is necessary.

Recently, the 3rd generation mobile communication system has been introduced. In addition to offering suitable data services (maximum bit rate of 2Mb/s in comparison with the 9.6 Kb/s of previous generation), this system provides a global standard for mobile communication. The 3rd generation receivers can be used throughout the world. In this regard the 8F study group of ITU is responsible for standardization of this generation of mobile communication systems. Wide band DS-CDMA has been accepted as the access technology and the 2 GHz frequency band is used for radio coverage area [3].

However, it seems that bit rates which are offered by the 3rd generation, are not enough for future users. In this regard studies has been started for the 4th generation mobile communication systems with 20 Mb/s bit rates. Orthogonal Frequency Division Multiple Access has been accepted as the access technology and its frequency band is wider than the previous generation [4].

With due regard to higher operating frequency bands and requirement of provision of services to mobile receivers, care must be taken into account in order to prevent and mitigate shadowing of obstacles.

In this paper, the properties of single frequency networks for radio coverage of the 4^{th} generation mobile communication systems will be investigated. Two networks containing 2 and 3 transmitters will be considered and their network gains with several shadowing conditions will be studied. In the second section of paper, the 4^{th} generation mobile communication system will be introduced. Then OFDM for mobile communication system will be discussed and the single frequency network and Network gain for SFN will be described. Finally Network gain for several shadowing conditions will be described in section 5 of the paper.

II. 4^{th} Generation Mobile Communication Systems

Contrary to other mobile communication systems, which have focused on defining new standards for mobile communication systems and implementing appropriate hardware for the adopted standard, the 4^{th} generation tries to integrate the available wireless services like WLAN, GSM and Bluetooth [2]-[5].

All of these systems have been developed for different bit rates and users. Therefore, implementation of the 4^{th} generation creates several problems. Reference [5] investigates these problems from the viewpoints of mobile terminals, system and service provision. From mobile terminal point of view, its receiver must be able to find, receive and select one of the available services. This problem can be overcome by software radio. From system point of view, relevant problems are mobility of receiver, possibility of selection of one service among the available services, quality of service, security and robustness. Finally, from service point of view, problems consist of the existance of multiple operators and their accounts, and possibility of usage of widespread receivers (like PC, PDA, Laptop).

It will be seen that SFN networks help the 4^{th}G mobile systems to reliably serve the mobile receivers and solve some problems from system point of view.

III. Orthogonal Frequency Division Multiple Access

In an OFDM based system, several carriers are used for transfer of information among transmitters and receivers. Each carrier carries a partial amount of information. Loss of a carrier causes loss of partial amounts of information, which can be recovered by appropriate coding of information.

Accordingly, information is arranged in spectral domain and then by inverse fast Fourier transform, it is obtained in time domain.

To improve the robustness of signal against multi-path, some of the information at the end of signal is added to the start of signal in time domain [6].

III. Single Frequency Networks

A single frequency network is a collection of transmitters, which cover an area with the same frequency. This network uses the benefits of OFDM to overcome the multi-path due to the guard interval at the end of OFDM frame. In the coverage area, the strongest signal from the main transmitter is considered as the main signal and the other signals as artificial echoes. Proper coverage is achieved, when the delays between the main signal and echoes are less than the guard interval.

In fact, due to OFDM properties, single frequency networks present transmitter diversity for the radio coverage. This diversity can help the coverage planners to efficiently cover blind points due to obstacles between transmitter and receiver. Blind spots of a transmitter overlays with coverage areas of other transmitters.

Diversity gain due to SFN (often referred to as network gain of SFN and measured with respect to one-transmitter network) helps the coverage planners to obtain uniform coverage with low power transmitters. This gain can be separated into the additive and statistical components. Additive terms represent the non-coherent summation signal levels from several transmitters. This summation is larger than the signal level from the main transmitter. Also, it is expected that for SFN, the field variations at an observation point are smaller than those from a single transmitter coverage area. Therefore, for adequate mobile coverage, less back up power is required for overcoming these statistical variations of field. This decrease in field level is referred to as the statistical gain of single frequency network.

IV. Determination of the Effect of SFN on Shadowing

Field experiments show that shadowing causes large variations of field level around the observation point. Shadowing can be modeled by the lognormal distribution as [7]

$$f_X(x) = \frac{1}{\sqrt{2\pi}\sigma_x} exp\left[-\frac{(20\log(x) - m)^2}{2\sigma_x^2} \right]$$

where m and σ_x are mean and standard deviation of the field amplitude in dB; m can be obtained by means of a simple propagation modeling method(i.e. 2 ray method,…). σ_x depends on object profiles and operating frequency. It is impossible to find the standard deviation theoretically and it must be determined by field tests. In this paper, we consider hypothetical values for the standard deviations. But exact coverage planning requires more field trials for accurate determination of these standard deviations.

Each receiver inside the coverage area of SFN networks receives signals from several transmitters with different statistical distributions.

Therefore, SFN modeling requires the summation of multiple lognormal variables.

V. Numerical Results

Two networks containing two and three transmitters (N=2,3) are considered for simulations. Field variations in these SFN networks are investigated. We use the Mont Carlo method for this purpose.

Figure 1 shows the probability distribution for 1, 2 and 3 field components with the same statistical parameters, which is computed by the Mont Carlo method. Because of the decrease of standard deviation of field for multi-transmitter networks, this example confirms our expectations for less variation of field level in the SFN network.

From this figure, it is seen that an additive network gain of 5.14 and 7.95 for networks with 2 and 3 transmitters, respectively are achieved. For 95% coverage, statistical gain is 2.84dB and 4.15dB for the aforementioned networks.

Fig. 2 shows the mean value of sum fields (for N=2 and 3) versus standard deviations of a selected field component, where the mean values of all components are kept constant. Fig. 3 shows the standard deviation of sum fields versus standard deviations of a selected field component, where the mean values of all components are kept constant.

We observe that both mean values curves are monotonic increasing functions of standard deviation of field components.

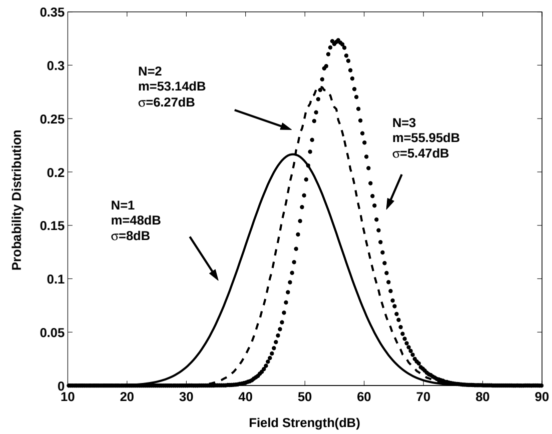

Fig.1 Probability Distribution of Sum of several Fields at a Typical SFN Network

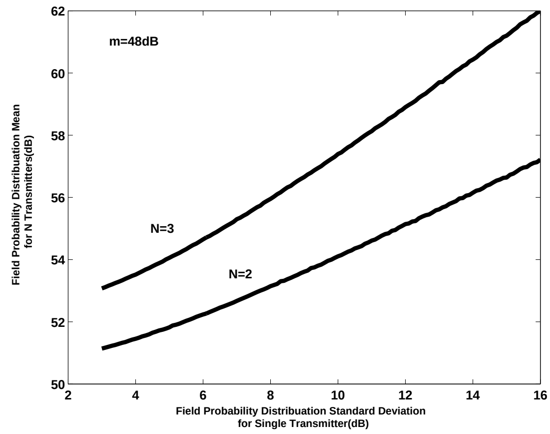

Fig.2 Mean value of Sum Field for Several Values of Standard Deviations of Constituent Components

Fig. 4 shows the mean value of sum field versus the mean value of a selected constituent component (with a constant standard deviation), which is a monotonic increasing function. Fig. 5 shows the standard deviation of the sum field versus the mean value of a selected constituent component (with a constant standard deviation), which is a concave function having a minimum point. The minimum point occurs when the mean values of constituent components are equal. Far away from this minimum, a component with larger mean value becomes the dominant component, and the statistical parameters of sum field are in the proximity of those of dominant component.

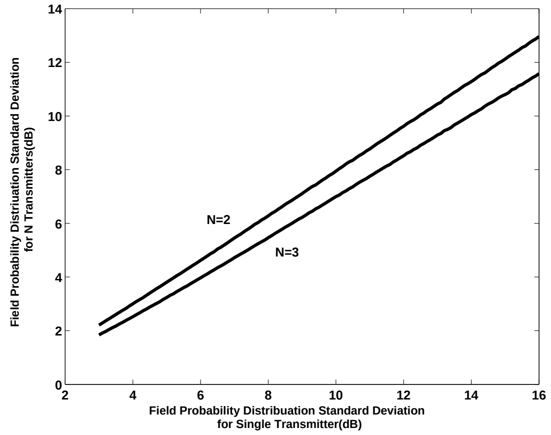

Fig.3 Standard Deviation value of Sum Field for Several Values of Standard Deviations of Constituent Components

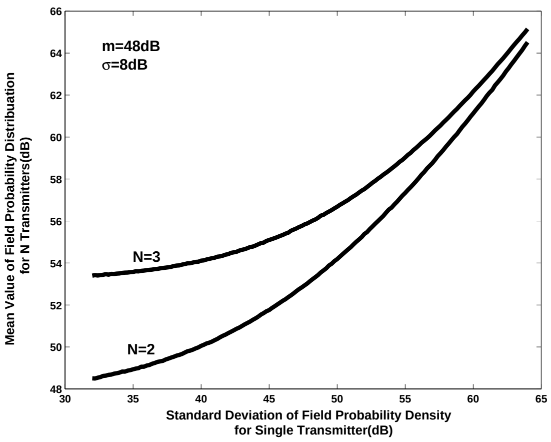

Fig.4 Mean value of Sum Field for Several Values of Mean for One of Constituent Components

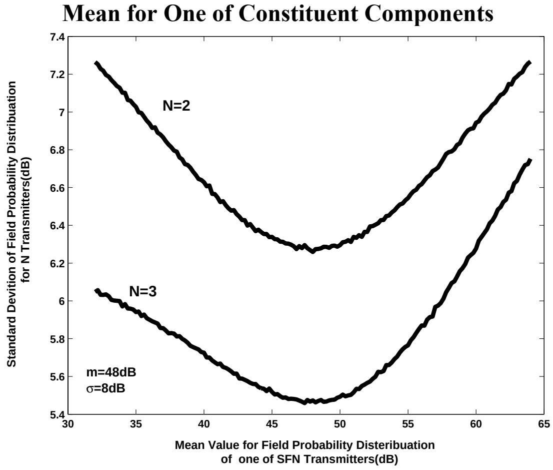

Fig.5 Standard Deviation value of Sum Field for Several Values of Means of Constituent Components

VI. Conclusion

The properties of SFN networks for the 4th generation mobile communication systems are investigated.

SFN introduces transmitter diversity, which helps the coverage planners to efficiently budget transmitter powers due to diversity gain and or network gain of SFN.

It is seen that by such network topologies, the reliability of 4G systems improves and blind spots in the coverage area of one transmitter can be covered with the other transmitters in the network.

Statistical simulations in the paper show that SFN network can mitigate the effect of shadowing due to obstacles and decreases the required back up power for acceptable radio coverage.

It is observed that statistical parameters of shadowing greatly affect wave propagation, in SFN networks and radio coverage. Therefore, precise SFN planning for the 4G mobile communication systems requires the extraction of shadowing parameters for various areas with variety of obstacles profiles.

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