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Spatial Modulation Technique For Filtered-OFDM Based Wireless Transmission

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A B S T R A C T

In this paper, a spatial modulation (SM) which provides no synchronization between the transmitting antennas and avoids inter-channel interference (ICI) at the receiver input while maintaining high spectral efficiency is applied to filtered-orthogonal frequency division multiplexing (F-OFDM) transmission. The SM technique maps a block of information bits into two information carrying units, namely, a symbol chosen from a signal constellation diagram and a unique antenna number selected from the set of transmit antennas. Therefore, for F-OFDM wireless transmission, each subcarrier within the subband is mapped to one of the transmitting antennas. During wireless data transmission, there is only one active antenna transmitting power on that subcarrier at an instant of time and the rest of the antennas remains silent (zero power). At the receiver, a maximum-likelihood (ML) detector recovers the transmitted block of information bits by estimating the transmitted signal and the respective transmit antenna number. The effectiveness of the proposed method is verified using numerical results.

1 Introduction

The unprecedented increase of mobile communications, wireless Internet access and multi-media applications has been driven by telecommunications companies and researchers to conceive new transmission technologies, protocols, and network infrastructure solutions in order to maximize both throughput and spectral efficiency [1]. For the next generation of wireless communication, it has become necessary to provide higher data rate and improve spectral efficiency. Employing multi–antennas at transmitter and receiver has shown to be an effective technique to achieve spectral efficiency over the past few years. The use of spatial multiplexing using multiple input multiple output (MIMO) was first proposed in [2]. MIMO technology is one of the techniques employed to attain high spectral efficiency by transmitting multiple data streams from multiple antennas [3]. However, the MIMO transmission is dependent on transmit and receive antenna spacing [4, 5], synchronization of the transmit antenna [6], as well as the algorithm needed for inter-channel interference (ICI) reduction at the receiver input. The Bell Labs Layered Space-Time Architecture (BLAST) in [7] proposed MIMO detection algorithms, named vertical BLAST (V-BLAST) [8]. In V-BLAST, multiple data streams are transmitted separately and detected successively by employing both an array processing (nulling) and interference cancelation techniques.

OFDM is another promising technique proposed for transmitting high speed data over wireless channels in future mobile communication systems [9]. OFDM has been useful in several wireless standards, for example, digital audio and video broadcasting (DAB) and (DVB-T), IEEE 802.11a [10], the IEEE 802.16a metropolitan area network (MAN), and the local area standard (LAN) [11]. Although, OFDM features seems attractive, there is still technical challenges that needs to be addressed for future wireless transmission [12, 13].

Recently, a new extension to OFDM has been proposed, namely, F-OFDM in [12, 13]. The most significant difference of F-OFDM, as opposed to the conventional OFDM, is that the former total bandwidth has been divided into multiple subband. In addition, each subband have a distinct subcarrier spacing with its own cyclic prefix (CP) and filter. On the other, in conventional OFDM, total bandwidth consists of a single block and has the same subcarrier spacing between the individual subcarriers. Note that, there is de-

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gree of flexibility in F-OFDM than its counterpart OFDM. The details can be found in [12, 13].

Therefore, in this paper, SM is applied to F-OFDM, namely, spatial modulation F-OFDM (SM F-OFDM), which provides higher spectral efficiency as a result of both SM and F-OFDM advantages. The main contributions of this work can be summarized as follows: (i) Analogue to [9], SM F-OFDM is designed for wireless transmission. (ii) Binary phase shift keying (BPSK) and quadrature amplitude modulation (QAM) modulation schemes were adopted for SM mapping rule.

The remaining sections are organized as follows: In Section II, the system model of SM-F-OFDM is presented. Simulation results are provided in Section III and concluding summaries are drawn in Section IV.

Throughout the paper, the following notations are used. Bold lowercase and bold uppercase letters denote vectors and matrices, respectively. We use $[.]^T$ and $\|.\|_F$ to denote transpose and Frobenius norm of a matrix or a vector, respectively. $\hat{i}(k)$ is the estimated transmit antenna index (number) and $\hat{x}_{\hat{i}}(k)$ is the estimated transmitted symbol. F-OFDM modulator-1 contains data belong to first antenna and so forth and $\otimes$ denotes time convolution.

2 System Model of SM F-OFDM

In this section, SM is discussed briefly. Suppose the total number of transmit and receive antennas is denoted by N_t and N_r respectively, M being the cardinality of the signal constellation. Hence, the rate of SM (bits per channel use - (bpcu)) for arbitrary N_t and M respectively, can be given by [14],[15]

$$R_{SM} = \log_2(N_t) + \log_2(M) \tag{1}$$

where $\log_2(N_t)$ defines the single active transmit antenna and $\log_2(M)$ is the transmitted QAM/BPSK modulation symbols. Note that the N_t, N_r and M, respectively, can be chosen independently [16]. The basic principle of SM is that, it maps multiple information bits into one information symbol with respect to their corresponding transmit antenna number. The number of information bits that can be transmitted in SM technique depends on the signal constellation diagram employed as well as the given number of transmit antennas. It is important to note that the SM utilizes the distinctiveness and random nature of the wireless channel for communication. The following summarized SM characteristics [14]:

1) At any signaling time instance, only one transmit antenna is active for data transmission while the other antennas remains silent.

2) The spatial position of each transmit antenna of the set is employed as an information source.

The proposed architecture of SM F-OFDM system is depicted in Figure 1, with the F-OFDM transmitter showing in Figure 2, while F-OFDM receiver is illustrated in Figure 3. Suppose the input $\mathbf{Q}(k)$ is $m \times n$ matrix which represents the transmitted symbols, where m is the total number of bits per symbol per subcarrier and n denotes the total number of subcarriers of the multiple subband of F-OFDM system. By using the SM mapping rule as listed in Table I, this matrix is mapped into $\mathbf{X}(k)$ of size $N_t \times n$.

From Table I, the SM mapping rule, maps each column in $\mathbf{Q}(k)$ into 4QAM and BPSK signal constellations respectively. In addition, one transmit antenna from a set of two (QPSK) and four (BPSK) antennas is assumed. Herein, 4QAM and BPSK modulation schemes were adopted in this work. As can be seen in Table I, the encoding mechanism are $N_t = 2$ and $M = 4$ when QAM is adopted. Note that, three information bits can be mapped onto 4-QAM with two transmit antennas selected. Similarly, for BPSK, the same spectral efficiency can be achieved with $N_t = 4$ and $M = 4$. Thus the F-OFDM system can convey three bits in each time slots. The number of information bits that can be transmitted on each F-OFDM subcarriers is given in (1). According to the SM mapping rule, the matrix $\mathbf{Q}(k)$ has one nonzero element in each column at the position of the mapped transmit antenna number. All the other elements in that column are defined as zero. It is worth mentioning that, when $N_t = 1$ simplifies SM F-OFDM to conventional single antenna communications.

Supposing in Figure 1, an input bit sequence of $[0 \;\; 0 \; 1]^T$ (column vector in $\mathbf{Q}(k)$) from Table I, is mapped to the QAM symbol - 1 + j and the first transmit antenna by using SM mapping. Thus only the first antenna transmits this symbol on the first F-OFDM subcarrier, whereas other antenna remains silent (zero power). As a result, the first column vector in $\mathbf{X}(k)$ is $[-1 + j \quad 0]^T$. The second bit sequence is $[1 \;\; 1 \; 0]^T$ and is mapped to $[0 \quad -1 - \mathrm{j}]^T$, and so on. Similarly, the same approach is adopted for BPSK symbols. The resultant symbols in each row vector $\mathbf{x}_v(k)$ are the data that will be transmitted on all subcarriers from transmit antenna v. And F-OFDM modulator will be used to modulate each row vector $\mathbf{x}_v(k)$.

At the F-OFDM modulator output, $\mathbf{s}_v(t)$ vector is generated. Each $\mathbf{s}_v(t)$ vector generated has a unique and disjoint set of F-OFDM subcarriers. The resulting output vectors at the F-OFDM modulator will be transmitted simultaneously from the N_t over the channel $\mathbf{H}(t)$. At the receiver, the received matrix $\mathbf{Y}(t)$ can be expressed as

$$\mathbf{Y}(t) = \mathbf{H}(t) \otimes \mathbf{S}(t) + \mathbf{G}(t) \tag{2}$$

where $\mathbf{S}(t)$ is a matrix that has all F-OFDM symbols that are transmitted from all transmit antennas. $\mathbf{G}(t)$ is the additive noise matrix, in which each element is assumed to be an independent and identically distributed (iid) zero mean complex Gaussian random variable with variance σ_N^2. $\mathbf{H}(t)$ is the $N_r \times N_t$ channel matrix between transmit antennas v and receive antennas k, respectively and can be expressed as (3)

$$\mathbf{H}(t) = \begin{pmatrix} h_{1,1}(t) & h_{1,2}(t) & \cdots & h_{1,N_r}(t) \\ h_{2,1}(t) & h_{2,2}(t) & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_r,1}(t) & h_{N_r,2}(t) & \cdots & h_{N_r,N_t}(t) \end{pmatrix} \tag{3}$$

where $\mathbf{h}_{k,v}$ is a complex fading coefficient between the v^{th} transmit antenna and k^{th} the receive antenna. $\mathbf{h}_{k,v}$ is as-

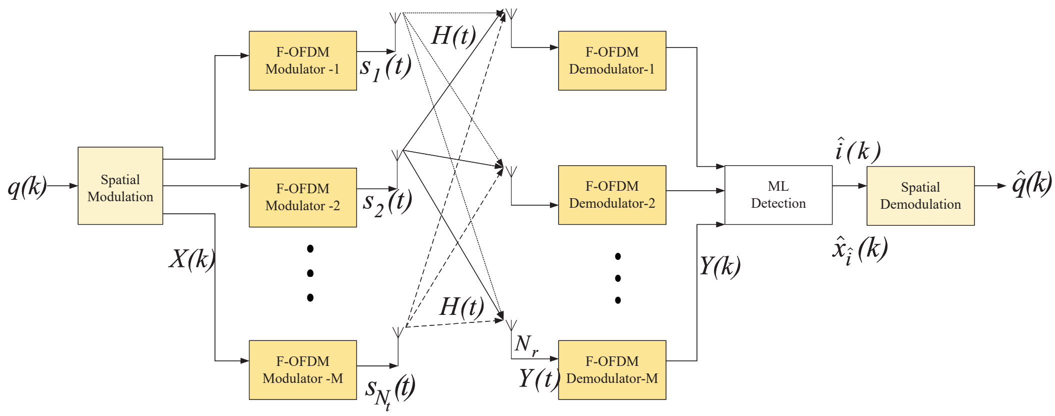

Figure 1: Proposed architecture of Spatial Modulation F-OFDM System for wireless transmission.

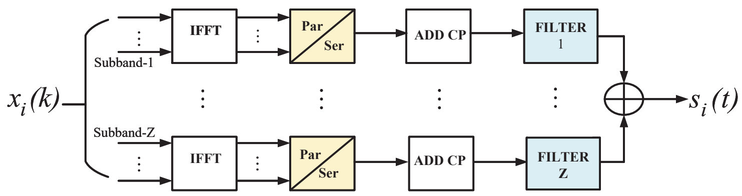

Figure 2: Block diagram of F-OFDM Transmitter.

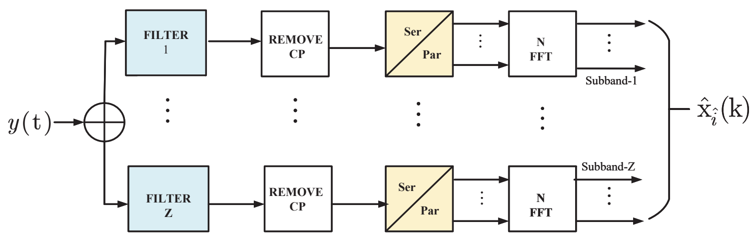

Figure 3: Block diagram of F-OFDM Receiver.

Table 1: Adopted SM F-OFDM Mapping Rule (3 bpcu).

	QAM		BPSK	
Input bits	Antenna Number	Transmit Symbol	Antenna Number	Transmit Symbol
000	1	+1+j	1	-1
001	1	-1+j	1	+1
010	1	-1-j	2	-1
011	1	+1-j	2	+1
100	2	+1+j	3	-1
101	2	-1+j	3	+1
110	2	-1-j	4	-1
111	2	+1-j	4	+1

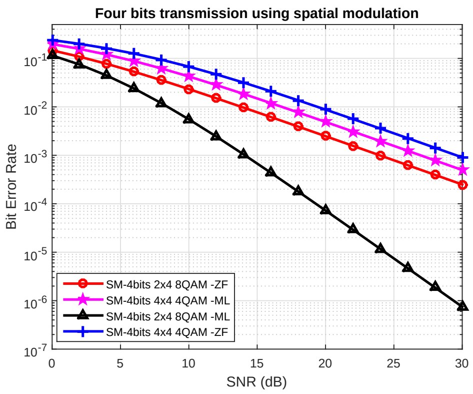

Figure 4: Illustration of BER performance for 4 bits per subcarrier employing ML and ZF detectors.

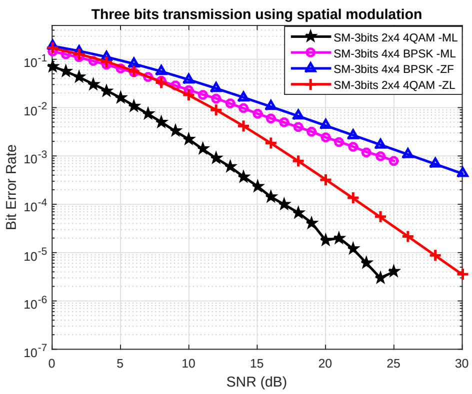

Figure 5: Illustration of BER performance for 3 bits per subcarrier employing ML and ZF detectors.

sumed to be iid complex zero mean Gaussian with variance one.

The receiver uses maximum likelihood detector to estimate the index, $\hat{i}(k)$ and the transmitted symbol, $\hat{x}_{\hat{i}}(k)$ can be expressed as

$$\begin{aligned} \left[\hat{i}^{\partial}, \hat{x}^{\partial}\right] &= \arg\max_{i,x} \Pr\left(Y_{\partial} \middle| H(t), \hat{x}_{\hat{i}}\right) \\ &= \arg\min_{i,x}\left(\left\| Y_{\partial} - H(t), \hat{x}_{\hat{i}} \right\|_F^2\right) \end{aligned} \tag{4}$$

where $\mathbf{Y}_{\partial}$ is the output matrix from the ML for the subcarrier ∂, i.e. $(\partial : 1, 2, ..., n)$ and

$$\Pr\left(\mathbf{Y}_{\partial} \middle| \mathbf{H}(t), \hat{x}_{\hat{i}}\right) = \frac{1}{\pi^{N_r} \sigma_N^{2N_r}} \exp\left[\frac{\left\| \mathbf{Y}_{\partial} - \mathbf{H}(t), \hat{x}_{\hat{i}} \right\|_F^2}{\sigma_N^2}\right] \tag{5}$$

is the conditional probability density function (PDF) of $\mathbf{Y}_{\partial}$ given $\mathbf{H}(t)$ and $\mathbf{x}_{\hat{i}}$. Equation (4) estimates both the transmit antenna number and the transmitted symbols jointly. The SM demodulator, then used these two estimates to extract the transmitted information bits on this subcarrier by taking an inverse mapping process adopted by the same mapping table used at the transmitter.

Similarly, the zero forcing (ZF) detector can be written as

$$\left[\widehat{i}^{\partial}, \widehat{x}^{\partial}\right] = \left(\left(\mathbf{H}^T(t)\mathbf{H}(t)\right)^{-1}\mathbf{H}(t)\right) * \mathbf{x} \tag{6}$$

where $\mathbf{x}$ denotes the transmitted symbol vector, $\mathbf{H}^T(t)$ is the transpose of the channel matrix in (3) and $*$ denotes the convolution.

3 Simulation Results and Discussions

In this section, simulation results for the proposed SM F-OFDM transmission is shown. Monte Carlo simulations is used to evaluate bit error rate (BER) performance utilizing maximum likelihood (ML) detector at the receiver. In addition, zero forcing (ZF) detector was employed for comparison. Herein, it was considered that the receiver have full channel knowledge and the receive antennas are separated wide enough to avoid correlation. Flat Rayleigh fading channel was also assumed.

3.1 Three Bits Transmission

By using different configurations, a three bits per subcarrier transmission can be achieved. For SM, a 4×4 BPSK and 2×4 4QAM configuration convey three bits per subcarrier. In Figure 4, SM 4×4 BPSK shows performance degradation as compared to SM 2×4 4QAM when ML detector is used. A similar trend can be observed for ZF detector as the same degradation performance is seen with the same configurations. The results in Figure 4 shows that the ML detector estimation outperforms ZL detector estimation.

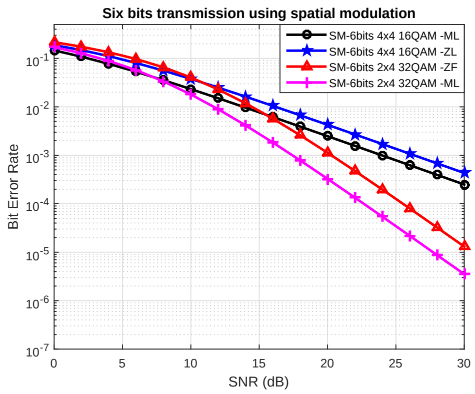

Figure 6: Illustration of BER performance for 6 bits per subcarrier employing ML and ZF detectors.

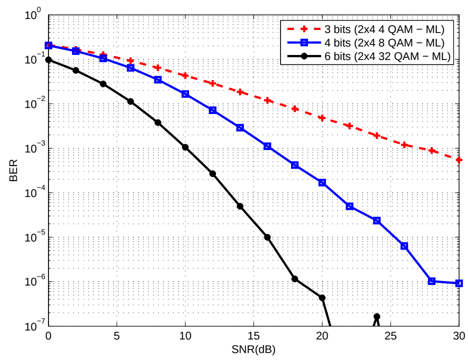

Figure 7: BER comparison performance for SM bits transmission, namely, 3, 4 and 6 bits, respectively when ML is adopted.

3.2 Four Bits Transmission

Four bits transmission can be achieved by the employment of SM 4×4 4QAM or 2×4 8QAM configuration. The comparison BER results in Figure 5 shows that the ZF demonstrates the worst performance as compared to ML detector.

3.3 Six Bits Transmission

Figure 6 results extended the simulation to a spectral efficiency of 6 bpcu for SM 4×4 16QAM or 2×4 32QAM transmissions. Again, ML detection outperforms ZF detection. It can be observed that the likelihood of errors for antenna detection increases with an increase in the number of transmit antennas. Therefore, the 2×4 SM system outperforms 4×4 system at high SNR. An interesting feature of SM can be noticed in Figure 6, where the 2×4 32QAM for ZF detector BER curve crosses the 4×4 16QAM ML detector at around 16 dB. This effect is a result of two estimation processes which is performed in SM, thus antenna number and transmitted symbol. Note that, the error level is dominated by the estimation of the transmitted symbol for low SNR, while the error level is dominated by the estimation of the transmit antenna number for a relatively high SNR. Hence, the scenario shown in Figure 6, for $SNR < 16dB$, lower constellation size and higher number of transmit antenna array is better for improved performance. On the other hand, for $SNR > 16dB$, higher constellation size and lower number of transmit antenna array is better. So there is a flexible tradeoff in this regard.

Figure 7 illustrates the BER comparison for distinct SM bits transmission, namely, 3 bits, 4 bits and 6 bits, respectively, for QAM modulation scheme. It can be observed that the 6 bits SM transmission performs better than the 3 bits and 4 bits. Thus $6bits > 4bits > 3bits$. This is because higher data rate can be achieved in the SM 6 bits transmission leading to a higher spectral efficiency.

4 Conclusion

In this paper, spectral efficient multiple antenna transmission technique, namely, spatial modulation (SM) is applied to F-OFDM for wireless transmission. The antenna pattern is considered as a spatial constellation in an innovative fashion by using SM technique to increase the spectral efficiency. By computer simulation, BER performance for the proposed scheme was evaluated for uncorrelated Rayleigh fading channel and compared with ZF detector. The proposed SM F-OFDM achieves a constant spectral efficiency in bits per subcarrier. Another significant merit of employing SM is the possibility of interchanging the constellation size and number of transmit antenna array to achieve better performance with respect to the operating SNR. In a follows up work, this feature will be further exploited. Furthermore, the performance improvement of the system increases as the transmission rate increases, which makes it a potential candidate for high data rate transmission systems. In addition, due to the estimation processes in SM approach, it is worth investigating further new algorithms for detection to improve the performance.

Conflict of Interest The author declare no conflict of interest.

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References

[1] Marco D. R, Harald H., Ali G., Shinya S., and Lajos H., "Spatial Modulation for Generalized MIMO: Challenges, Opportunities, and Implementation ". *Proceedings of IEEE*, pp. 1–47, 2013.

[2] Mehdi Maleki Pirbazari, "Space Modulation: Signal design and performance evaluation" . *PhD dissertation – University of Akron*, 2015.

[3] E. Telatar, "Capacity of Multi-Antenna Gaussian Channels". *European Transaction Telecommunication*, vol. 10, no. 6, November/December pp. 558-595, 1999.

[4] G. J. Foschini, M. J. Gans, and J. M. Kahn, "Fading Correlation and its Effect on the Capacity of Multielement Antenna Systems". *IEEE Transactions on Communications*, vol. 48, March, pp. 502-513, 2000.

[5] S. Loyka and G. Tsoulos,, "Estimating MIMO System Performance Using the Correlation Matrix Approach" . *IEEE Communications Letters*, vol. 6, no. 1, pp. 19-21, January 2002.

[6] Marco. Chiani, Moe Z. W., and A. Zanella, "On the Capacity of Spatially Correlated MIMO Rayleigh-Fading Channels". *IEEE Transactions on Information Theory*, vol. 49, no. 10, pp. 2363-2371, October 2003.

[7] G. J. Foschini, "Layered SpaceTtime Architecture for Wireless Communication in a Fading Environment when Using Multi-Element Antennas". *Bell Labs Technical Journal*, vol. 1, no. 2, pp. 41-59, September 1996.

[8] P. W. Wolniansky, G. J. Foschini, G. D. Golden, and R. A. Valenzuela, "V-BLAST: An Architecture for Realizing Very High Data Rates Over the Rich-Scattering Wireless Channel". *Proceedings of the IEEE International Symposium on Signals, Systems, and Electronics (ISSSE)*, pp. 295-300, September/October 1998.

[9] R. Mesleh, H. Haas, C.W. Ahn and S. Yun, "Spatial Modulation OFDM". *In the Proceedings of the 11th International OFDM-Workshop 2006 (InOWO'06)*, pp. 288–292, August 30-31, 2006.

[10] IEEE, Part 11, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: High Speed Physical Layer in the 5 GHz Band". *IEEE Standard 802.11a*, 1999.

[11] IEEE, Part 16, "Local and Metropolitan Area Networks: Air Interface for Fixed Broadband Wireless Access Systems". *IEEE Standard 802.16a*, 2003.

[12] Xi Zhang, Ming Jia, Lei Chen, Jianglei Ma, Jing Qiu, "Filtered-OFDM Enabler for Flexible Waveform in The 5th Generation Cellular Networks". *Accepted to IEEE GLOBECOM, San Diego, CA*, pp. 16–20, Dec. 2015.

[13] Javad Abdoli, Ming Jia, and Jianglei Ma, "Filtered OFDM: A New Waveform for Future Wireless Systems ". *IEEE 16th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, pp. 60–70, 2015.

[14] M. Di Renzo, H. Haas, and P. M. Grant, "Spatial modulation for multiple-antenna wireless systems: A survey". *IEEE Communications Magazine*, vol. 49, no. 12, pp. 182-191, Dec. 2011.

[15] R. Y. Mesleh, H. Haas, S. Sinanovic, C. W. Ahn, and S. Yun, "Spatial modulation". *IEEE Transactions on Vehicular Technology*, vol. 57, no. 4, pp. 2228-2241, Jul. 2008.

[16] J. Mietzner, R. Schober, L. Lampe, W. H. Gerstacker, and P. A. Hoeher, "Multiple-antenna techniques for wireless communications – A comprehensive literature survey". *IEEE Communications Survey Tutorial*, vol. 11, no. 2, 2nd Quart. pp. 87-105, 2009.