Perfomance of Space-Time Coded OFDM Schemes in Land Mobile Satellite Channel

Oludare Sokoya, *Member, IAENG,* and B.T. Maharaj

***Abstract*—In this paper the performance of space-time coded-orthogonal frequency division multiplexing (STC-OFDM) schemes are examined in a land mobile satellite communication channel. The land mobile satellite channel is modeled using Loo's model. The frame error rate curve of the STC-OFDM schemes with and without the land mobile satellite channel is compared. For the land mobile satellite channel, increased performance in terms of coding gain is obtained for STC-OFDM schemes.**

***Index Terms*—Space-time codes, satellite communication channels, OFDM, diversity.**

I. INTRODUCTION

RECENTLY, there has been growing interest in the combination of satellite communication systems with terrestrial communication systems for broadcasting multimedia services to mobile user terminals. A satellite communication network offers a cost-effective system that provides wide area coverage, while a terrestrial network achieves connectivity to mobile terminals located in densely built environments.

The Interntional Telecommunications Union-Radiocommunication sector divides mobile satellite services (MSS) using both satellite and terrestrial components into two parts, i.e. hybrid and integrated systems.

In integrated MSS systems, the terrestrial part is complemetary and operates as part of the MSS system. This means that the satellite resources and management system also control the terrestrial component. The same portion of allocated spectrum is used by the satellite and the terrestrial part.

In hybrid system, althought the subsystems are interconnected, they operate independently of each other. This means that the satellite and terrestrial components have separate network management systems and they do not necessarily use the same spectrum. Emerging technologies that combine the complementing features of both satellite and terrestrial networks in building a cost-effective network with good quality of service include the multiple antennas in Digital Video Broadcasting-Terrestrial Second Generation (DVB-T2), DVB-NGH (Next Generation Handheld) and DVB-SH (Satellite Handheld) [1].

The design of some of these emerging technologies requires that they provide resistance to land mobile satellite channel (LMSC) impairments [2], [3] and ensure maximum spectral efficiency.

One way of maximising spectral efficiency while catering for channel impairment in LMSC, e.g. frequency selectivity, is to employ specially designed multiple antenna channel codes with OFDM, i.e. STC-OFDM schemes. These STC-OFDM schemes include Space-Time Block Coded-OFDM (STBC-OFDM) [4], Space-Time Trellis Coded-OFDM (STTC-OFDM) [5] and Super-Orthogonal Space-Time Trellis Coded-OFDM (SOSTTC-OFDM) [6].

In LMSC with frequency selectivity, channel codes for multiple antenna systems and OFDM can potentially exploit the possible multipath diversity. As a result of the multipath diversity, the maximum diversity possible for the channel codes in an OFDM environment is therefore a product of the number of transmit antennas and receive antennas and the channel impulse response length.

In this paper, the performance of STC-OFDM schemes in a land mobile satellite communication link is studied. The frame error rate performance of the STC-OFDM schemes, i.e. STBC-OFDM, STTC-OFDM and SOSTTC-OFDM, is studied in a land mobile satellite channel and compared with an uncoded OFDM system.

The outline of the paper is as follows: In section II, the land mobile satellite channel model used is briefly discussed. The design structure of the various STC-OFDM schemes is given in section III. The system structure is described in section IV. Simulation results are presented in section V, while conclusions are drawn in section VI.

II. LAND MOBILE SATELLITE CHANNELS - LOO'S MODEL

The design of a good communication system begins with a thorough understanding of the communication channel. The objective is to provide reliable communication that meets the quality of service objectives, without overdesigning the system. The LMSC is an integral part of the satellite communication system. The LMSC is susceptible to impairments such as, multipath fading, shadowing, doppler shift and interference.

Multipath fading happens owing to the scattering of the signal. Shadowing occurs when the signal is blocked by buildings, trees and hills. These blockages are common features in an urban environment and mountaineous regions. The relative velocity between the satellite and the mobile terminal causes the doppler shift. Interference is possible from terrestrial systems and other satellite systems and from self-interference, in the form of a multiple access environment.

The modelling of LMSC is an active area of research. In [7] and [8] a survey of the LMSC available in literature was done. The four main categories of channel models for LMSC

Manuscript received July 7, 2014; revised August 12, 2014. This work was supported in part by the Department of Electronic Engineering, Durban University of Technology, South Africa.

O. Sokoya is with the Department of Electronic Engineering, Durban University of Technology, Durban, KZN, 4000 South Africa e-mail: oludares@dut.ac.za.

B. T. Maharaj is the SENTECH Chair in the Broadband Wireless Multimedia Communication Group of the Department of Electrical, Electronic and Computer Engineering, University of Pretoria, Lynnwood, 0002, South Africa e-mail: sunil.maharaj@up.ac.za.

are analytical models [9] [10], empirical models [11], hybrid models [12] and statistical models [13].
Loo's model is an example of a statistical model [14]. It assumes that there are two signal distortion components that characterise the LMSC. The line of sight (LoS) component suffers from foliage attenuation and is log-normally distributed, while the multipath component's attenuation is Rayleigh distributed. The sum of a log-normally distributed random phasor and a Rayleigh phasor can be expressed mathematically as:

$$r\ \exp(j\theta) = z\ \exp(j\phi_0) + w\ \exp(j\phi) \tag{1}$$

where the phase ϕ_0 and ϕ are uniformly distributed between 0 and 2π, z is log-normally distributed , and w has a Rayleigh distribution. The signal envelope probability density function (pdf) for the mobiel satellite channel is given by:

$$p(r) = \frac{r}{b_0\sqrt{2\pi d_0}} \cdot \int_0^\infty \frac{1}{z} \exp\left(\frac{-(\ln z - \mu)^2}{2d_0} - \frac{r^2 + z^2}{2b_0} \right) . I_0\left(\frac{rz}{b_0}\right) dz \quad r \geq 0 \tag{2}$$

where $\sqrt{d_0}$ and μ are the standard deviation and mean of the log-normal pdf, respectively. b_0 represents the average scattered power due to multipath fading and $I_0(.)$ is the modified Bessel function of zeroth order. The pdf given in equation (2) becomes (3) when z is a constant A, such that is there is a clear LoS component with no shadowing but with multipath fading.

$$p(r) = \frac{r}{b_0} \exp\left(\frac{-(r^2 + A^2)}{2b_0} \right) I_0\left(\frac{rA}{b_0}\right), \quad r \geq 0. \tag{3}$$

If shadowing occurs but there is no multipath fading, the signal pdf will be log-normal and is given by:

$$p(r) = \frac{1}{r\sqrt{2\pi d_0}} \exp\left(\frac{-(\ln z - \mu)^2}{2d_0} \right), \quad r \geq 0. \tag{4}$$

When there is no LoS and shadowing component, the signal envelope pdf is Rayleigh distributed and is given by:

$$p(r) = \frac{r}{b_0} \exp\left(\frac{-r^2}{2b_0}\right), \quad r \geq 0. \tag{5}$$

III. The design structure of the various STC-OFDM schemes

Space-time coding schemes can be combined with OFDM in a wireless network to produce a system that can achieve spectral efficiency and increase throughput in such a network. A brief description of the STC-OFDM coded schemes is given in the following sections.The mathematical expressions assume multiple transmitters and a single receiver system. The expressions can be extended to a multiple receiver easily by using the oulined methods.

A. Space-Time Block Coded-OFDM

In general the orthogonal design of STBC is defined by a $n \times N_t$ transmission matrix $\mathbf{S}$ [15]. The entries of $\mathbf{S}$ are linear combination of the transmitted symbols and their conjugate. The transmission matrix representation of 2 $N_t = 2$ is given by:

$$\mathbf{S} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \tag{6}$$

where N_t is the number of transmit antenna and n is the size of the orthogonal matrix. At each time slot, which consists of n OFDM symbols, mb bits arrive at the encoder of subcarrier k and constellation symbols $s_{1,k}, \ldots, s_{m,k}$ are selected. Setting $x_i = s_i, k$ for $i = 1, 2, \ldots, m$ in $\mathbf{S}$, a matrix $\mathbf{S}_k$ for each subcarrier k is obtained. The receive signal matrix at two time slots and on the kth subcarrier for $N_t = 2$ is given by:

$$\begin{bmatrix} r_{1,k} \\ r_{2,k} \end{bmatrix} = \begin{bmatrix} s_{1,k} & s_{2,k} \\ -s_{2,k}^* & s_{1k}^* \end{bmatrix} . \begin{bmatrix} H_{1,k} \\ H_{2,k} \end{bmatrix} + \begin{bmatrix} \eta_{1,k} \\ \eta_{2,k} \end{bmatrix} \tag{7}$$

where $H_{i,k}$ is the channel frequency response for the i^{th} transmit antenna on the k^{th} subcarrier. The noise components at each subcarrier are represented by $\eta_{i,k}$.
The channel frequency response used in equation (7) can be expressed as a function of an fast Fourier transform (FFT) coeficient as:

$$\begin{aligned} H_{i,k} &= \sum_{l=0}^{L-1} h_i(l) \exp(-j2\pi k(l)/K) \\ &= \mathbf{h}_i \mathbf{f}(k) \end{aligned} \tag{8}$$

where L is the total number of non-zero taps of the fading channel and $\mathbf{h}_i$ comprises the channel vectors given in equation (9) as:

$$\mathbf{h}_i = [\ h_i(0),\ \ h_i(1),\ \ h_i(2),\ \ \cdots,\ \ h_i(L-1)\ ], \tag{9}$$

and the FFT coefficient can be expressed as:

$$\begin{aligned} \mathbf{f}(k) &= [\exp\frac{-j2\pi k(0)}{K}, \cdots, \exp\frac{-j2\pi k(L-1)}{K}]^T \\ &= [1,\ \cdots,\ f(L-1)]^T. \end{aligned} \tag{10}$$

B. Space-Time Trellis Coded-OFDM

STTC was invented by Tarokh et al. [16] as a technique that achieves both diversity and coding gain in multiple input multiple output (MIMO) flat fading channels. In frequency selective fading channel, STTC suffers from unreduceable floors of error probability due to the effect of intersymbol interference (ISI) on the multipath fading channel [17]. STTC in OFDM systems, i.e. STTC-OFDM, combats the effect of ISI by transforming the frequency selective fading channels in parallel correlated flat fading channels.
The performance of STTC-OFDM schemes has been investigated in the literature, [18], [19] and [20]. In [18] the performance of STTC-OFDM without interleavers in quasi-static frequency selective fading channel was presented. The coding gain of the STTC-OFDM under various channel conditions was presented. The analysis gives two main conditions that can be used to maximise the minimun determinant of the STTC-OFDM system over multiple tap channels. These are maximising the minimum determinant of the tap delay channel and increasing the memory order of the STTC system. Based on these conditions, a new 16-state STTC-OFDM was designed in [19].

ISBN: 978-988-19253-7-4
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

The received signal for an STTC-OFDM system on the k^{th} subcarrier is given by:

$$r_k = \sum_{i}^{N_t} H_{i,k} s_{i,k} + \eta_k \quad (11)$$

where $s_{i,k}$, $i \in \{1, 2, \ldots, N_t\}$, $k \in \{1, 2, \ldots, K\}$ is the encoded OFDM symbol, $H_{i,k}$ is the channel frequency response for the i^{th} transmit antenna on the k^{th} subcarrier. The noise components at each subcarrier are represented by η_k .

C. *Super Orthogonal Space-Time Trellis Coded-OFDM*

A new class of space-time codes, called super orthogonal space-time trellis codes, was introduced in [21]. These codes combine set partitioning and a super set of orthogonal space time block codes in a systematic way to provide full diversity and improved coding gain when compared with earlier space time trellis constructions [16]. SOSTTC not only provide a scheme that is an improvement in coding gain when compared with earlier constructions, but it also answers the question of a systematic design for any rate, number of states and the maximization of coding gain. The transmission matrix used in the design of SOSTTC for $N_t = 2$ is given by:

$$\mathbf{S}(s_1, s_2, \theta) = \begin{bmatrix} s_1 e^{j\theta} & s_2 \\ -s_2^* e^{j\theta} & s_1^* \end{bmatrix}. \quad (12)$$

In equation (12) $s_i \in e^{j\frac{2\pi \acute{a}}{M}}$ represents the M-PSK signal constellation. The angular rotation θ is equivalent to $2\pi\acute{a}/\mathrm{M}$ where $\acute{a} = 0, 1, \cdots, \mathrm{M} - 1$. Despite the angular rotation of the transmitted signal, the matrix elements of equations (12) are still members of the M-PSK constellation and the signal constellation is not expanded. For BPSK signal constellation, $\theta = 0$ or π while for a QPSK signal constellation, $\theta = 0$ or $\pi/2$ or π or $3\pi/2$. When θ in equation (12) is zero, the Alamouti code is obtained.

In an OFDM environment, a 16-state trellis, without parallel path, was designed for SOSTTC that fully exploits the spatial and multipath diversity of the code based on the pairwise error probability of the error difference symbol matrix [6]. The receive signal matrix at two time slots and on the kth subcarrier for $N_t = 2$ is given by:

$$\begin{bmatrix} r_{1,k} \\ r_{2,k} \end{bmatrix} = \begin{bmatrix} s_{1,k} e^{j\theta} & s_{2,k} \\ -s_{2,k}^* e^{j\theta} & s_{1,k}^* \end{bmatrix} \begin{bmatrix} H_{1,k} \\ H_{2,k} \end{bmatrix} + \begin{bmatrix} \eta_{1,k} \\ \eta_{2,k} \end{bmatrix}. \quad (13)$$

IV. System Structure

The general structure of the simulated system can be seen in Figure 1. In Figure 1, the multiple antenna system with OFDM transmits independent OFDM modulated data from multiple antennas at the same time. At the receiver, after OFDM demodulation, multiple antenna system decoding is done on each of the subchannels by extracting the data from all the transmit antennas on all the subchannels. Loo's channel model was used, in the hybrid system, as it takes into account the direct as well as the diffuse-multipath component of the channel property.

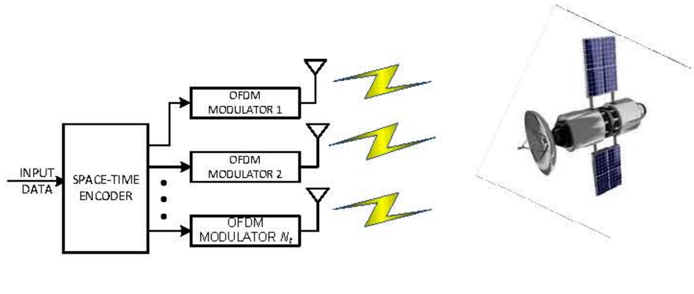

Fig. 1. System Structure

V. Simulation Results

The proposed system simulation is shown to demonstrate the frame error rate (FER) performance of the STC-OFDM schemes, i.e., STBC-OFDM, STTC-OFDM and SOSTTC-OFDM in a terrestrial environment and a hybrid environment. The channel in the terrestrial enviroment was modelled as a quasi-static frequency selective Rayleigh fading channel with $N_t = 2$, $N_r = 1$, $L = 2$ and an equal delay profile, while in the hybrid environment Loo's mobile-satelite model was used. The total power of the transmitted coded symbol was normalized to unity and a frame length of 256 bits was used at the transmitter. The trellis structures for the STTC-OFDM systems are given in Figures 2 and 3, while for SOSTTC-OFDM systems, the trellis structures are given in Figures 4 and 5.

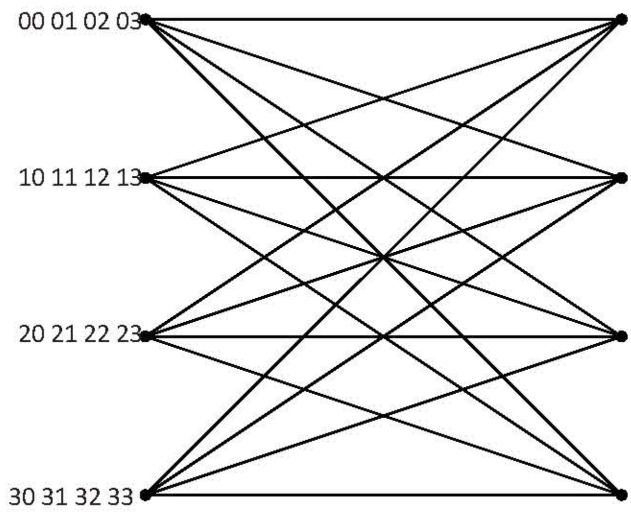

Fig. 2. 4-State QPSK STTC-OFDM Trellis

In Figures 6, 7 and 8, the FER performance of STC-OFDM schemes and uncoded OFDM with and without an LMSC model is given. The figures show that there is a coding gain advantage of the STC-OFDM schemes in an hybrid environment (i.e. with LMSC) as compared to the terrestrial environment (i.e. without LMSC). This is evident in the downward shift of the FER curves. In the figures, it is also apparent that an uncoded OFDM transmission with LMSC yields slightly better performance than one without LMSC. When STC-OFDM schemes are applied the system performs even better. The performance gain of the STC-OFDM schemes in the hybrid environment can be attributed to the coding gain provided by the schemes and the LOS

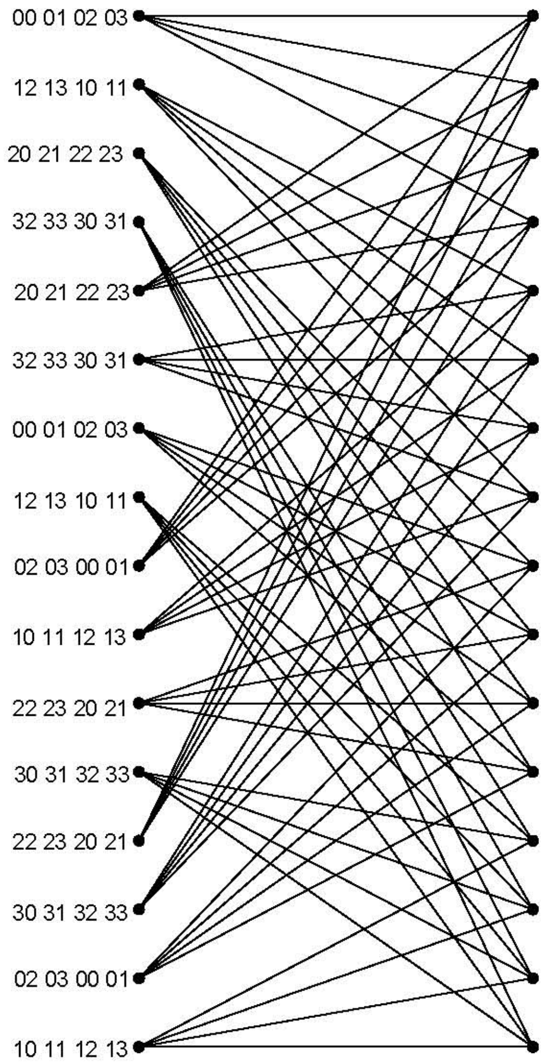

Fig. 3. 16-State QPSK STTC-OFDM Trellis

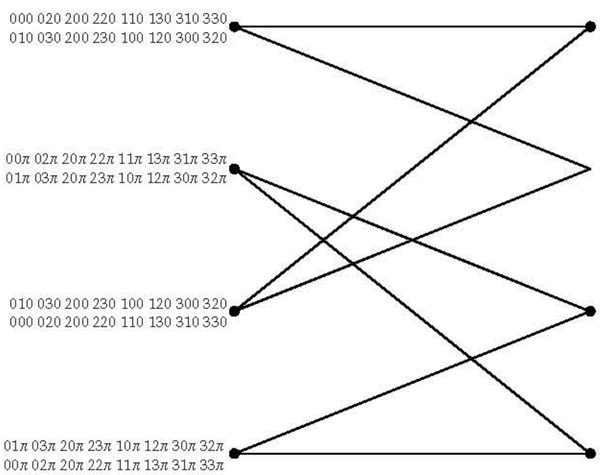

Fig. 4. 4-State QPSK SOSTTC-OFDM Trellis

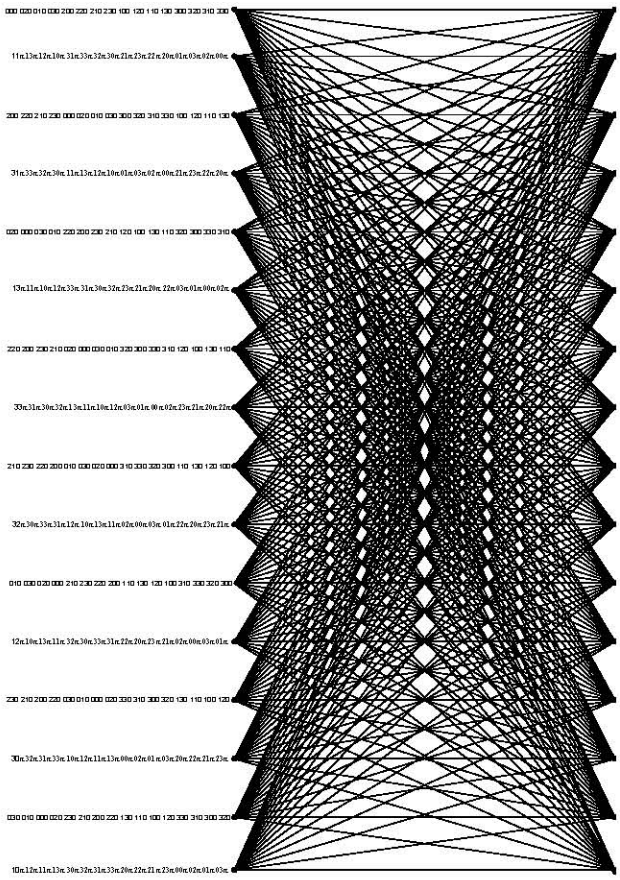

Fig. 5. 16-State QPSK SOSTTC-OFDM Trellis

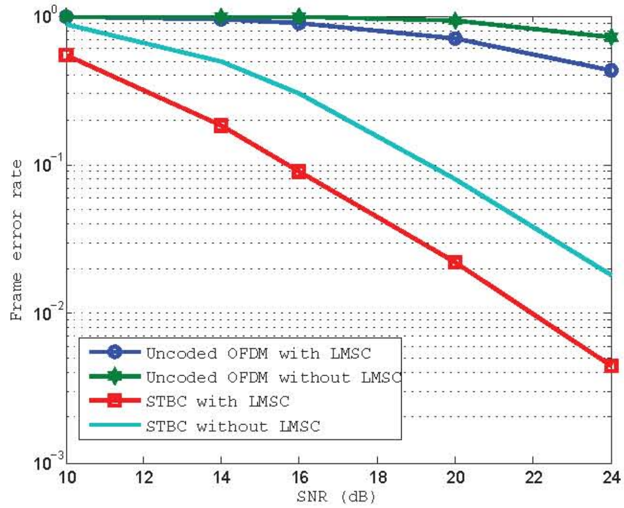

Fig. 6. FER performance of QPSK STBC-OFDM with and without LMSC

component of the LMSC model.

VI. Conclusion

In this paper the FER performance of STC-OFDM schemes, i.e. STBC-OFDM, STTC–OFDM and SOSTTC-OFDM, in both a terrestrial environment and a hybrid environment, is considered. The STC-OFDM schemes appear to be quite beneficial in terms of FER performance in the hybrid environment. The STC-OFDM schemes show an increased coding gain advantage in the hybrid environment compared to the terrestrial environment. In general this study demonstates

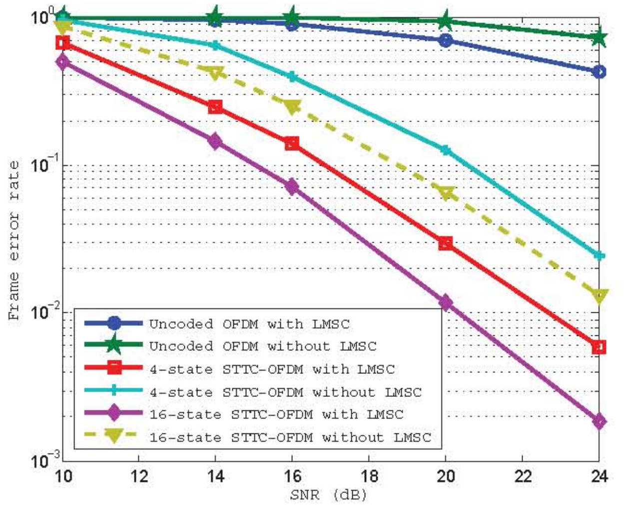

Fig. 7. FER performance of QPSK STTC-OFDM with and without LMSC

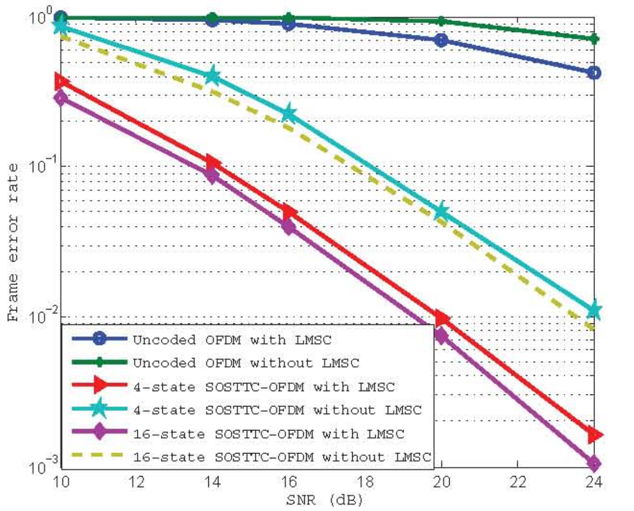

Fig. 8. FER performance of QPSK SOSTTC-OFDM with and without LMSC

that hybrid satellite environment can profit a lot when STC-OFDM schemes are incoporated in its design.

REFERENCES

[1] Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for satellite transmission to handheld. (DVB-SH) *ETSIEN 302 583 V1.0.0,* June 2007.

[2] F. Perez-Fontan, M. Vazquez-Castro, C. Cabado, and E. K. J.P. Garcia, "Statistical modeling of the LMS channel," *IEEE Transactions on Vehicular Technology*, vol. 50, no. 6, pp. 1549–1567, 2001.

[3] A. B. Alamanac, P. Burzigotti, R. D. Gaudenzi, G. Liva, H. N. Pham, and S. Scalise, "In-depth analysis of the satellite component of DVB-SH: Scenarios, system dimensioning, simulations and field trial results," *Internationa Journal of Satellite Communication Network*, vol. 27, no. 4–5, pp. 215–240, 2009.

[4] G. Bauch, "Space-time block codes versus space-frequency block codes," in *Proceedings of the IEEE Vehicular Technology Conference*, Seoul, Korea, April 2003, pp. 567–571.

[5] Y. Hong and et. al., "Performance analysis of space-time trellis coded OFDM system," in *Proceedings of IEEE Vehicular Technology Conference*, vol. 2, Stockholm, Sweden, May 2005, pp. 1176–1180.

[6] K. Aksoy and U. Aygolu, "Super-orthogonal space-time frequency trellis coded OFDM," *IET Communication*, vol. 1, no. 3, pp. 317–324, June 2007.

[7] M. Karaliopoulos and F. N. Pavlidous, "Modelling the land mobile satellite channel: a review," *Electronic Communication Engineering Journal*, vol. 11, no. 5, pp. 235–248, October 1999.

[8] G. S. Hoffmann, A. S. J. Helberg, and M. J. Grobler, "A brief survey of channel models for land mobile satellite communication," in *Proceedings of Southern Africa Telecommunication Application Network*, Stellenbosch, South Africa, September 2010.

[9] M. Dottling, A. Jahn, and W. Wiesbeck, "A new wideband model for the land mobile satellite propagation channel," in *Proceedings of the IEEE International Conference on Universal Personal Communications*, October 1998, pp. 647–651.

[10] T. Sofos, I. Koutsopoulos, and P. Constantinou, "A deterministic ray-tracing based model for land mobile satellite channel in urban environment ," in *Proceedings of the IEEE Conference on Vehicular Technology*, vol. 1, May 1998, pp. 658–660.

[11] N. Moratis, V. Milas, and P. Constantinou, "On the empirical model comparison for the land mobile satellite channel," in *Proceedings of IEEE Vehicular Technology Conference*, April 2007, pp. 1405–1409.

[12] T. Sofos and P. Constatinous, "Propagation mode for vegetation effects in terrestrial and satellite mobile systems," *IEEE Transactions on Antennas Propagation*, vol. 52, no. 7, pp. 1917–1920, July 2004.

[13] T. Gillespie and C. Robertson, "An improved markov model for the urban sotm channel," in *Proceedings of the IEEE Military Communication Conference*, November 2008, pp. 1–8.

[14] C. Loo and J. Butterworth, "Land mobile satellite channel measurements and modeling," in *Proceedings of the IEEE*, vol. 86, July 1998, pp. 1442–1463.

[15] V. Tarokh, H. Jafarkhani, and A. R. Calderbank, "Space-time block codes from orthogonal designs," *IEEE Transactions on Information Theory*, vol. 45, pp. 1456–1467, July 1999.

[16] ——, "Space-time codes for highr data rate wireless communication; Performance analysis and code construction," *IEEE Transactions on Information Theory*, vol. 44, no. 2, pp. 744–756, March 1998.

[17] Y. Gong and K. B. Letaief, "Performance evaluation and analysis of space-time coding in unequalised multipath fading links," *IEEE Transactions on Communications*, vol. 48, no. 11, pp. 1778–1782, November 2000.

[18] Y. Hong, J. Choi, and X. Shao, "Performance analysis of space-time trellis coded OFDM over quasi-static frequency selective fading channel," in *Proceedings of the 2003 Joint Conference of the Fourth International Conference on Information, Communications and Signal Processing and Fourth Pacific Rim Conference on Multimedia*, vol. 3, Singapore, December 2003, pp. 1478–1482.

[19] ——, "Robust space-time trellis codes for OFDM systems over quasi-static frequency selective fading channels," in *Proceedings of IEEE Personal, Indoor and Mobile Radio Communications Conference*, vol. 1, Beijing, China, September 2003, pp. 434–439.

[20] H. Bolcskei and A. J. Paulraj, "Space-frequency coded broadband OFDM systems," in *Proceedings of IEEE Wireless Communications and Networking Conference*, Chicago, USA, September 2000, pp. 1–6.

[21] H. Jafarkhani and N. Seshadri, "Super-orthogonal space-time trellis codes," *IEEE Transactions on Information Theory*, vol. 49, pp. 937–950, April 2003.

Oludare Sokoya received his BSc (Eng) degree in 2001 from the School of Electronic and Electrical Engineering at the Obafemi Awolowo University, Nigeria, MSc(Eng) from University of KwaZulu-Natal in 2005 and a PhD in Electronic Engineering from the University of Pretoria. He has worked with various institutions which include; Philips Project Centre, Nigeria, Meraka Institute, South Africa and ZTE Corporation South Africa. He is currently a Senior lecturer at the Durban University of Technology. His research interests are in advanced physical layer technologies for wireless communication.

B.T. Maharaj received his BSc (Eng) and MSc(Eng) in Electronic Engineering from the University of Natal (Durban). He received an MSc in Operational Telecommunications with merit from the University of Coventry and a PhD in Wireless Communications from the University of Pretoria. Professor Maharaj currently holds the position of Sentech Chair in Broadband Wireless Multimedia Communications in the Department of Electrical, Electronic and Computer Engineering at the University of Pretoria. His research interests are in MIMO channel modelling, OFDM-MIMO systems and cognitive radio. .