IQ Space Frequency Time Codes for MIMO-OFDM Systems

Samir Al-Ghadhban
Brian Woerner
R. Michael Buehrer
samir@kfupm.edu.sa
http://faculty.kfupm.edu.sa/EE/samir/

IEEE VTC Spring 2006, Melbourne, Australia

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY
MPRG
MOBILE & PORTABLE RADIO RESEARCH GROUP

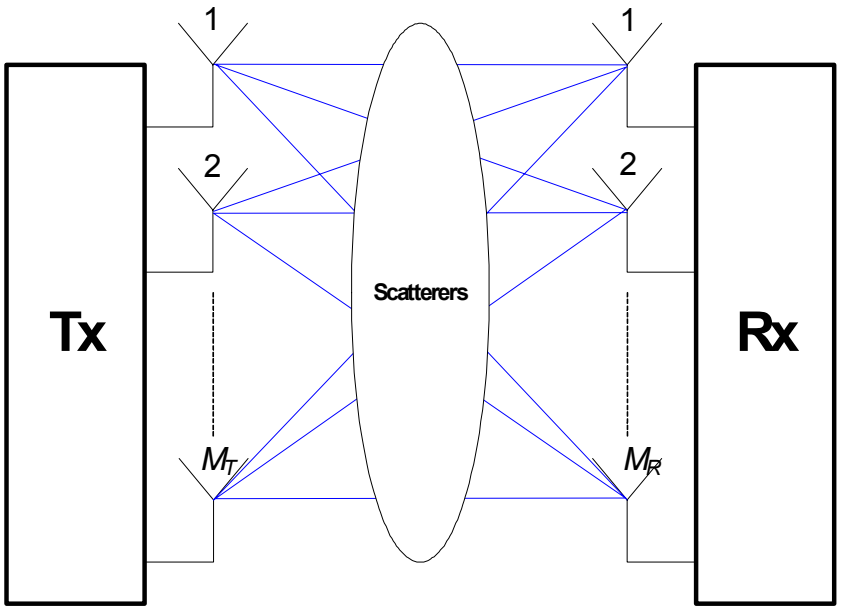
Virginia Tech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Outline

- Background and motivation
- IQ-SFT code description and performance
- Effect of interleaving

Introduction: Multiple Input Multiple Output (MIMO) Channels

- A MIMO channel is a wireless link between *MT* transmit and *MR* receive antennas.
- MIMO channels boost the information capacity of wireless systems by order of magnitude [Telater95][Foschini98].



$$\mathbf{H}(t) = \begin{pmatrix} h_{11}(t) & \cdots & h_{1M_T}(t) \\ \vdots & \ddots & \vdots \\ h_{M_R 1}(t) & \cdots & h_{M_R M_T}(t) \end{pmatrix}$$

OFDM

- Wide bandwidth and high data rates result in frequency selective channels (FSC) which cause ISI.
- OFDM is robust against FSC. It transforms FSC to parallel flat fading channels.
- WLANs such as IEEE 802.11a and Hyperlan2 are based on OFDM

OFDM Channel Model in the Frequency Domain

N_c subcarriers
L taps (FSC length)

Let $\mathbf{h}_{mn} = [h_0 \quad h_1 \quad \cdots \quad h_{L-1}]^T$

The OFDM channel in the frequency domain is $\mathbf{h}^f_{mn} = \mathbf{F}\mathbf{h}_{mn}$

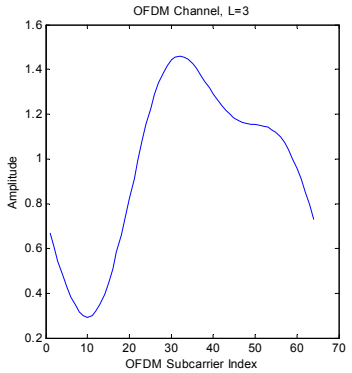
$$\mathbf{F}_{k,l} = \frac{1}{\sqrt{N_c}} \exp\left[-i \frac{2\pi}{N_c}(k-1)(l-1)\right];$$

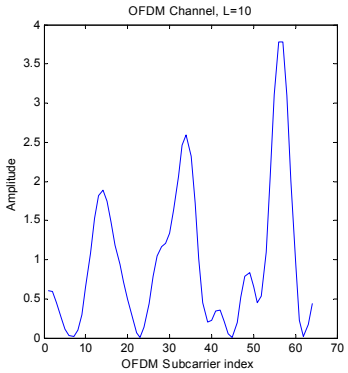
$k = 0,1,...,N_c - 1$

$l = 0,1,...,L-1$

Let $\mathbf{h} \sim N_c(\mathbf{0}, \mathbf{C}_\mathbf{h})$

The covariance matrix in the frequency domain is $\mathbf{C}_{\mathbf{h}^f} = \mathbf{F}\mathbf{C}_\mathbf{h}\mathbf{F}^H$





Background on Space Frequency Time (SFT) Codes

- SFT codes apply spatial coding across multiple antennas, frequency coding across OFDM subcarriers, and temporal coding across successive OFDM symbols.
- [Agrawal98]: STTC-OFDM, not optimized for OFDM channels, designed for quasi-static channels.

Design criteria of SFT codes

- The maximum diversity available in MIMO-OFDM systems is $M_T L M_R$ [Ben Lu 2000].
- The design criterion is to maximize the minimum effective length and break up channel correlation in frequency domain by interleaving.
- To achieve this diversity, the minimum effective length of the SFT code should be equal to at least $M_T L$, which needs large number of states for practical values.

Design criteria of SFT codes

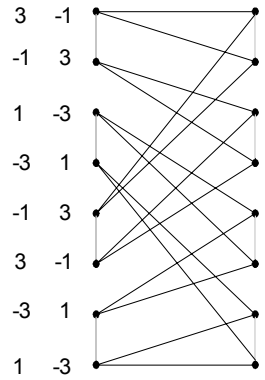
- Our goal in this work is to simplify the design and reduce the number of states required to achieve the full spatial and frequency diversity.
- Our approach is to concatenate trellis coded modulation (TCM) and STBC.
- Spatial diversity is guaranteed by STBC and frequency diversity is provided by TCM.
- We further reduce the number of states of TCM by using IQ-TCM [AlSemari 97].

IQ-TCM [AlSemari97]

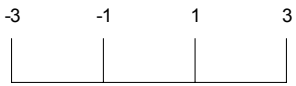
- The minimum effective length of TCM is upper bounded by:

$$l_{\min} \le \lfloor v / k \rfloor + 1$$

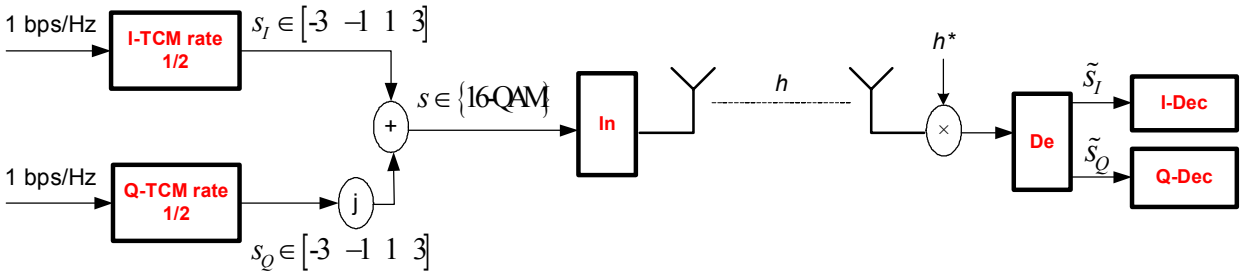
8-states 4AM-TCM



In: Interleaver
De: De-interleaver

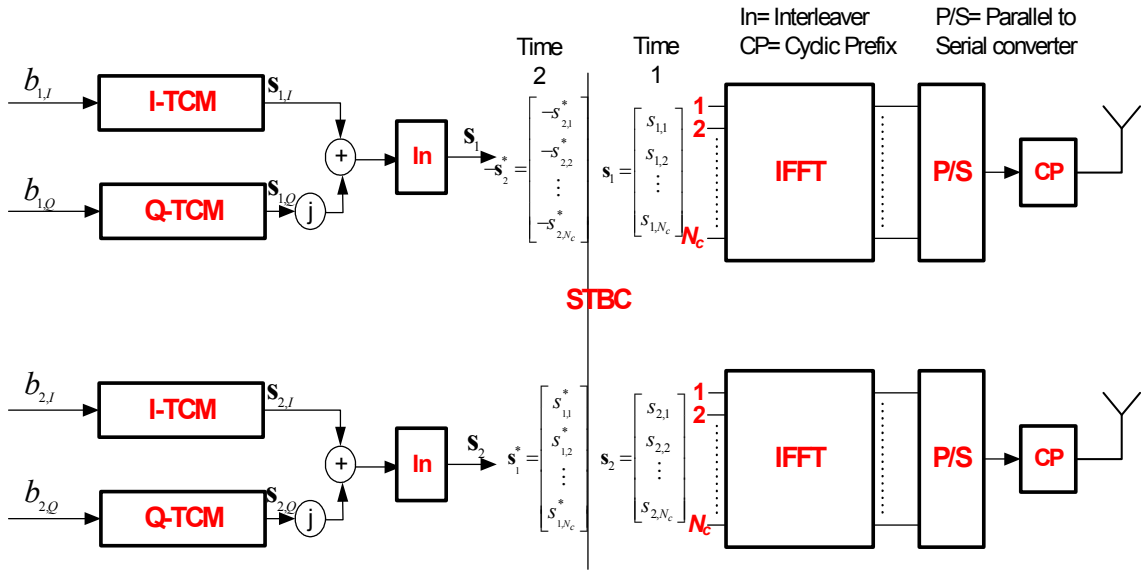


2 bps/Hz IQ-16QAM-TCM

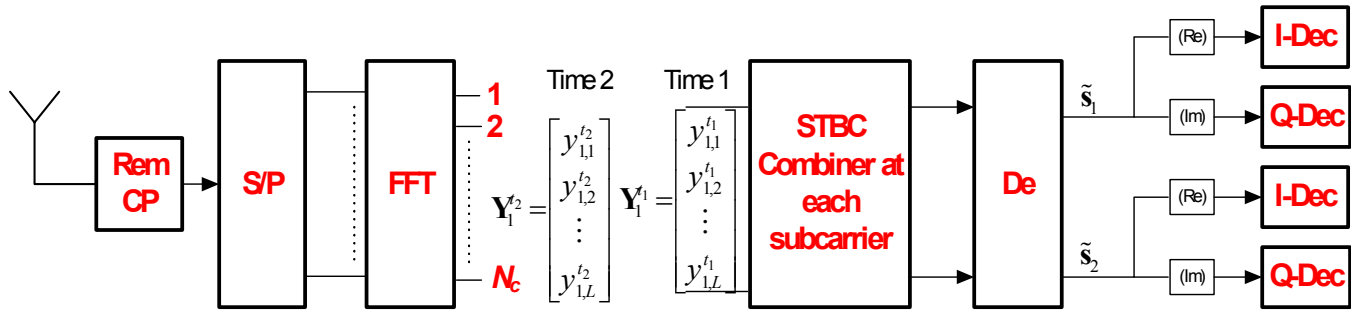


IQ-SFT

Encoder



Decoder



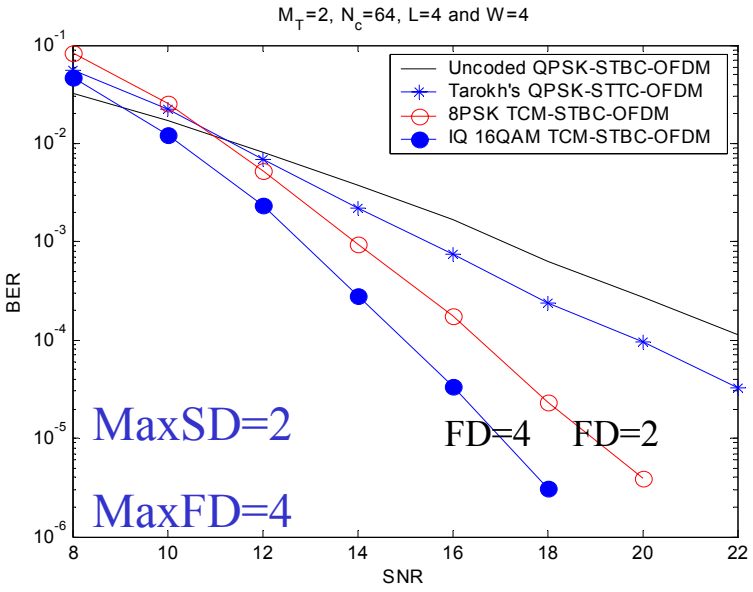
Advantages of concatenated IQ-TCM-STBC at 2bps/Hz

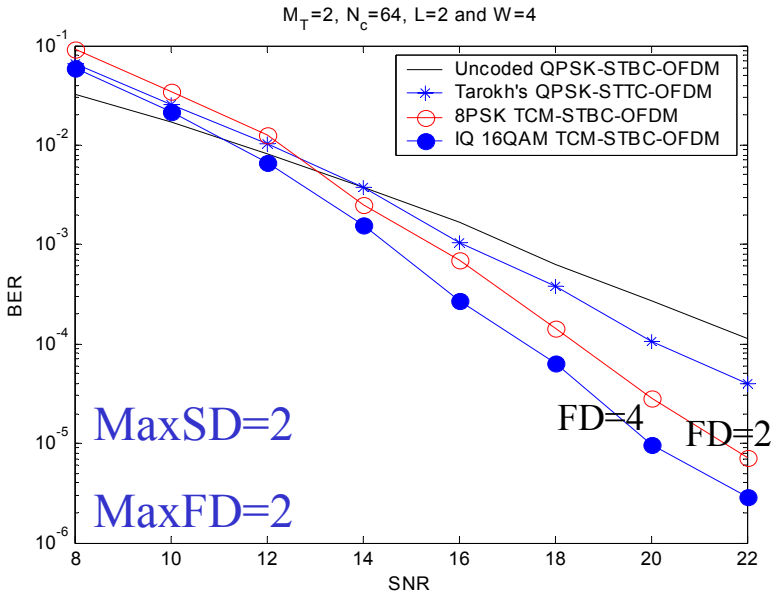
FCS Length	Minimum number of states to achieve full diversity ($M_T L M_R$)		
L	Tarokh STTC QPSK	8PSK-STBC	IQ-16QAM-STBC
2	64	4	2
3	1024	16	4
4	16384	64	8
5	262144	256	16
6	4194304	1024	32
7	67108864	4096	64

Channel Model

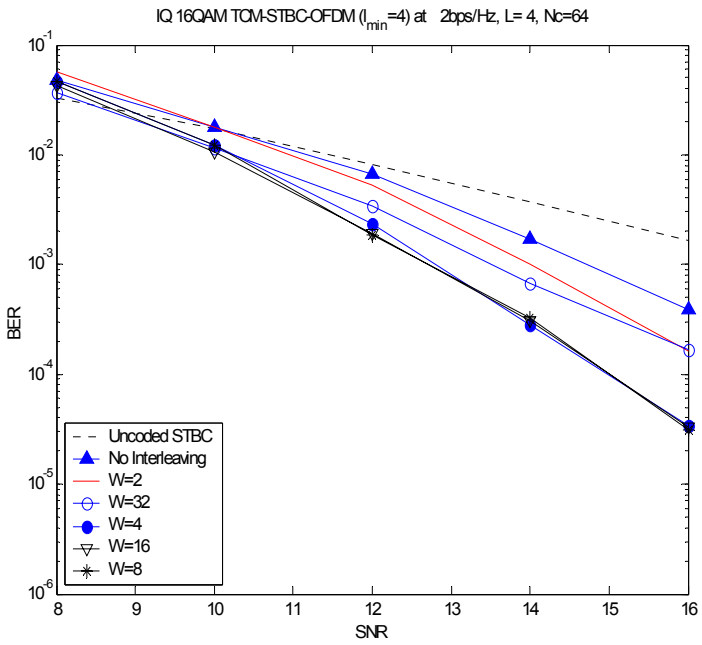
- The channel is a MIMO-FSC of length L with equal power paths and each path experience an independent Rayleigh fading.
- We assume that the channel is constant over two OFDM symbols.

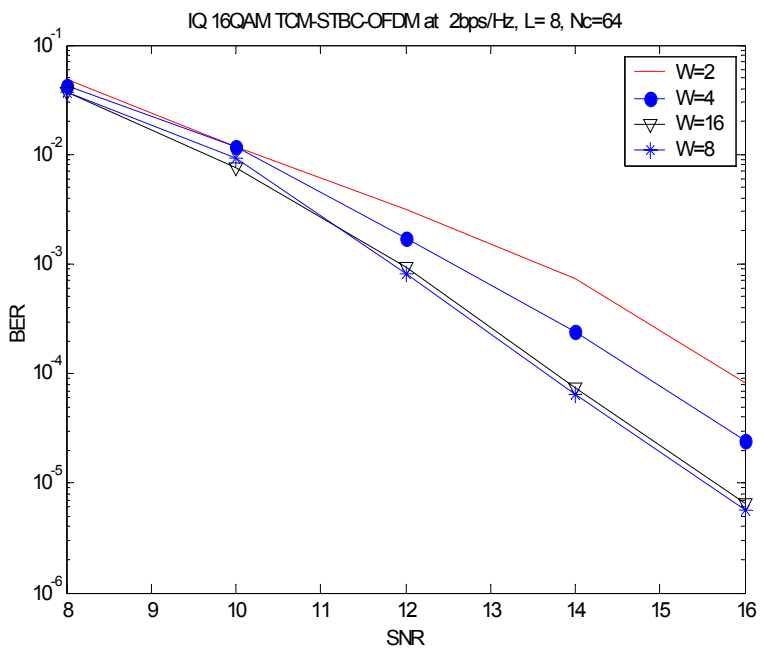
Performance results over 2x1 MIMO-OFDM channels at 2 bps/Hz 8-state TCM, N_c=64, W=4



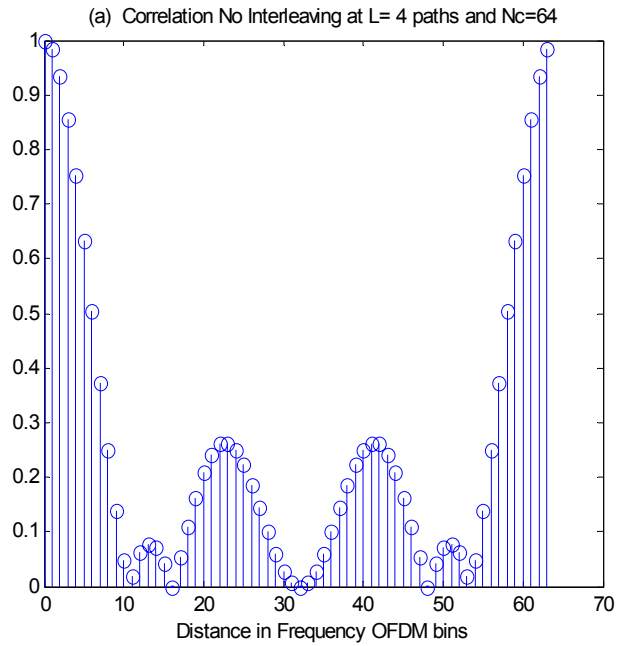


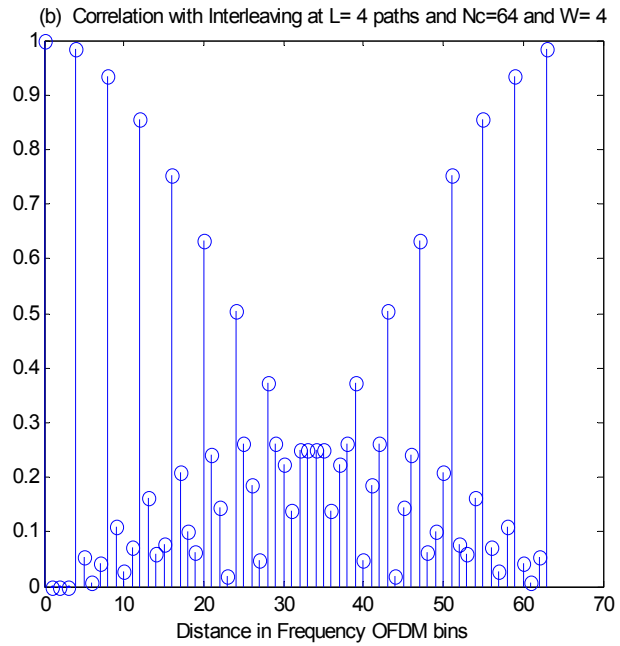
Interleaving effect over 2x1 MIMO-OFDM channels at 2bps/Hz 8-state TCM





Effect of interleaving on subcarrier correlation





SFT coding conclusions

- Concatenated IQ-TCM-STBC-OFDM achieves full spatial and frequency diversity at much lower complexity than other codes.
- Appropriate block interleaver design is essential to maintain the performance and diversity of the code. Best performance is at W=L and W=2L.

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY

MPRG

MOBILE & PORTABLE RADIO RESEARCH GROUP

Virginia Tech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY