Broadband Wireless Access and MIMO

Hailin Zhang
Liqiang Zhao

- Introduction to our research team
- Broadband wireless access systems in near space
- Advanced MIMO detector
- Interpolation based precoding with limited feedback for MIMO-OFDM systems

Introduction to Our Research Team

Hailin Zhang

2 professors
4 associate professors
5 lecturers
over 10 PhD students

Liqiang Zhao
Yongzhao Li
…

Xiaofeng Lu
Yi Liu
…

Depin Wu
Longwei Liu
…

Broadband Wireless Access
Cooperative Communication

MIMO Technologies

Engineering Implementation

Dean, Professor, Dr. Hailin Zhang

- He has supervised over 20 PhD students. Some have become leading experts in the field of wireless communications.
- His current research focuses on broadband wireless transmission technologies, e.g., MIMO.
- He has won many research projects funded by a number of sources: government and direct industrial funding. His participation in various projects has yielded a number of concrete results including enormous high-level publications, patents, etc.
- Due to his excellent works in education and research, he was awarded several honor titles by the government.

Professor, Dr. Liqiang Zhao

- His current research focuses on broadband wireless access, wireless mesh network, and wireless sensor network.
- He is hosting 4 projects from the government.
- He has published over 60 referred papers in the various journals and conferences.
- Due to his excellent works in education and research, he was awarded by the Program for New Century Excellent Talents in University, Ministry of Education, China, in 2008.

Mr. Wenchi Cheng

- He received his BS. Degree in Telecommunication Engineering in 2008 and from 2008 – now, Ph.D. students in Xidian University.
- He got the second round (Top 200 of the world) of 2007 Imagine Cup Microsoft Embedded Development Competition and the second prize of 2007 National Undergraduate Electronic Design Competition.
- He has published one paper in SiC, the top journal in China, and one international conference paper.
- His current research interests include MIMO and cross-layer design in wireless networks.

Team Photo

Funding

- Currently, the team is hosting
  - three large projects from Advance Research Program,
  - one large project from the 13115 Project,
  - one Natural Science Foundation project,
  - two projects from State Key Lab. of Integrated Services Networks,
  - three projects from the industry.

Research Topics

- Our research covers almost the whole spectrum of broadband wireless access, such as routing and MAC protocols, and PHY technologies.
  - Key Technologies of Broadband Wireless Integrated Access Systems
  - Key Technologies of MIMO Systems
  - Linearization of Broadband Memorized Transmitters
- Our research covers an interdisciplinary research topic, introducing game theory from mathematics and economics into wireless communications.
  - Research on Game-theoretic MAC Protocols in WSNs

Related Papers

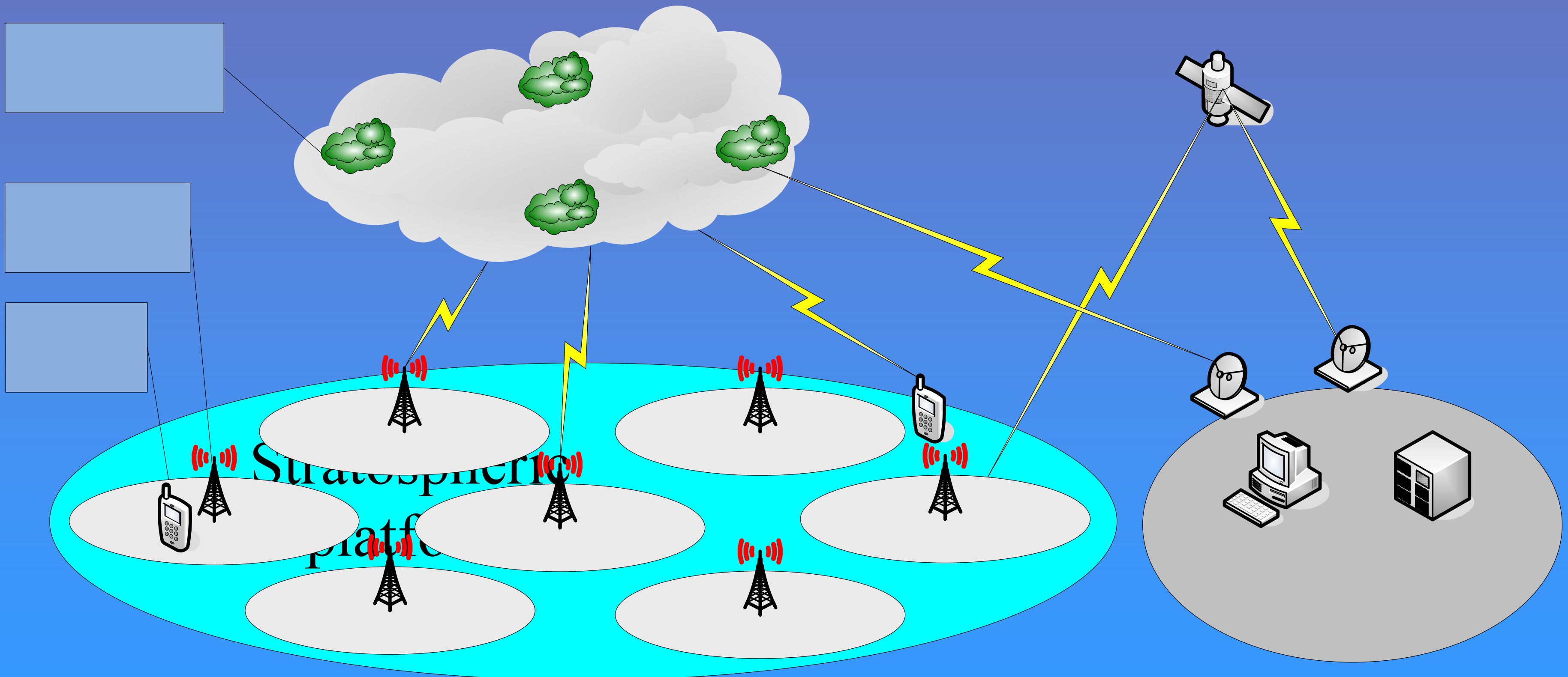
- X. Lei, L. Zhao, G. Zhang, and H. Zhang, Joint Time-Frequency-Power Resource Allocation Algorithm for OFDMA Systems, Submitted to *Mobile Networks and Application*.
- W. Cheng and H. Zhang, Approximating Maximum Likelihood Performance Reduced Dimension VBLAST Detection Algorithm, To appear in *Science in China Series F - Information Sciences*.
- L. Cong, L. Zhao, et al, A Stackelberg Game for Resource Allocation in Multiuser Cooperative Transmission Network, Accepted by *Wiley Journal of Wireless Communications and Mobile Computing*.
- L. Zhao, J. Zhang, and H. Zhang, Using Incompletely Cooperative Game Theory in Wireless Mesh Networks, *IEEE Network Magazine*, January/February 2008, Vol. 22, No. 1, pp. 39-44.
- Y. Liu and H. Zhang, Interpolation Based Precoding with Limited Feedback for MIMO-OFDM Systems, *IET Communications*, Aug. 2007, Vol. 1, No. 4, pp. 679-683.

Related Patents

- TD-OFDMA-based dynamic hierarchical structure and frame format of broadband wireless PMP/Mesh access systems, submitted.
- Low complexity VBLAST detecting method approaching ML performance, submitted.
- A linearization method and equipment in broadband wireless communication systems, submitted.
- Iterative decoding method for VBLAST, submitted.
- Inter-synchronization in mobile ad hoc networks, approval.
- Token transmission and management methods for wireless ad hoc networks, 200510041684.

- Introduction to our research team
- Broadband wireless access systems in near space
  - Research topics
  - Research results achieved
- Advanced MIMO detector
- Interpolation based precoding with limited feedback for MIMO-OFDM systems

Broadband Wireless Access System in Near Space



Ground base-station

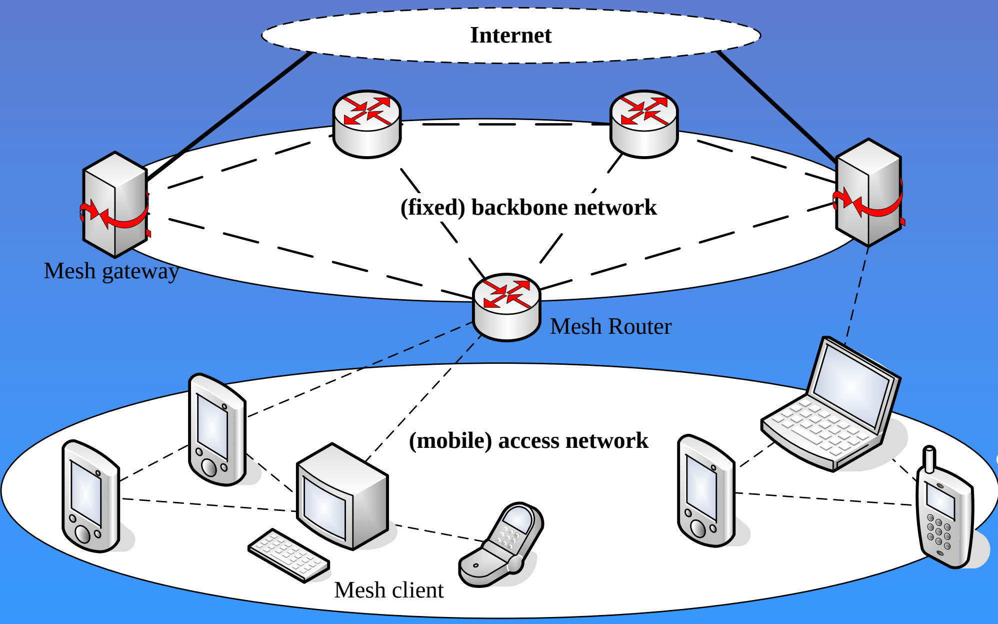
Research Topics

- Low-medium attitude platform based air-ground broadband wireless PMP/Mesh hybrid networks
- Routing and MAC protocols for hierarchy broadband wireless cooperative mesh networks
- Fusion strategies in heterogeneous networks
- Integration of multiple systems in the aerial platforms
- Resource management and access control in broadband wireless access systems
- Stratospheric telecommunication platform based adaptive multi-beam antennas

Research Results Achieved

- Broadband wireless PMP/Mesh access structure is proposed.
- Layered network topology and active/on-demand routing protocols are investigated.
- The frame format which supports PMP/Mesh hybrid access are proposed.
- Synchronization strategy and uplink channel estimation strategy for PMP/Mesh broadband wireless access network are proposed.
- Demonstration prototype of broadband wireless PMP/Mesh hybrid networks is under investigation.

Hierarchy Wireless Mesh Networks

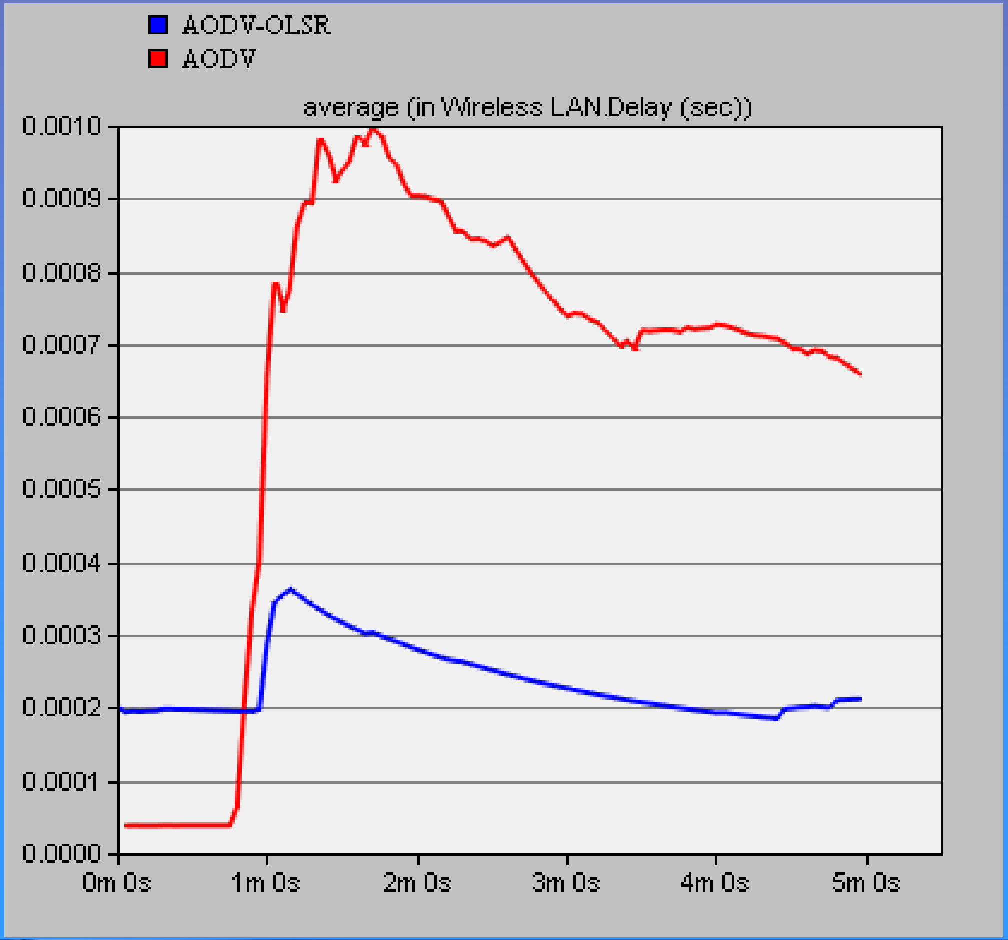


- In hierarchy WMNs, the backbone network is composed of mesh routers with minimal mobility and little energy restriction, and the access network is composed by mesh clients with high mobility and energy restriction.
- The mobile clients roam among the routers, and the backbone connects to Internet via mesh gateways.

Hybrid Routing Protocols

- To take full advantages of hierarchy WMNs, we presented a novel hybrid routing protocol, i.e., proactive routing protocols (e.g., OLSR) for the backbone network and on-demand routing protocols (e.g., AODV) for the access network.
- We are developing advanced hybrid routing protocols for cooperative WMNs, e.g., considering the cost of the cooperative relaying when designing the payoff function.

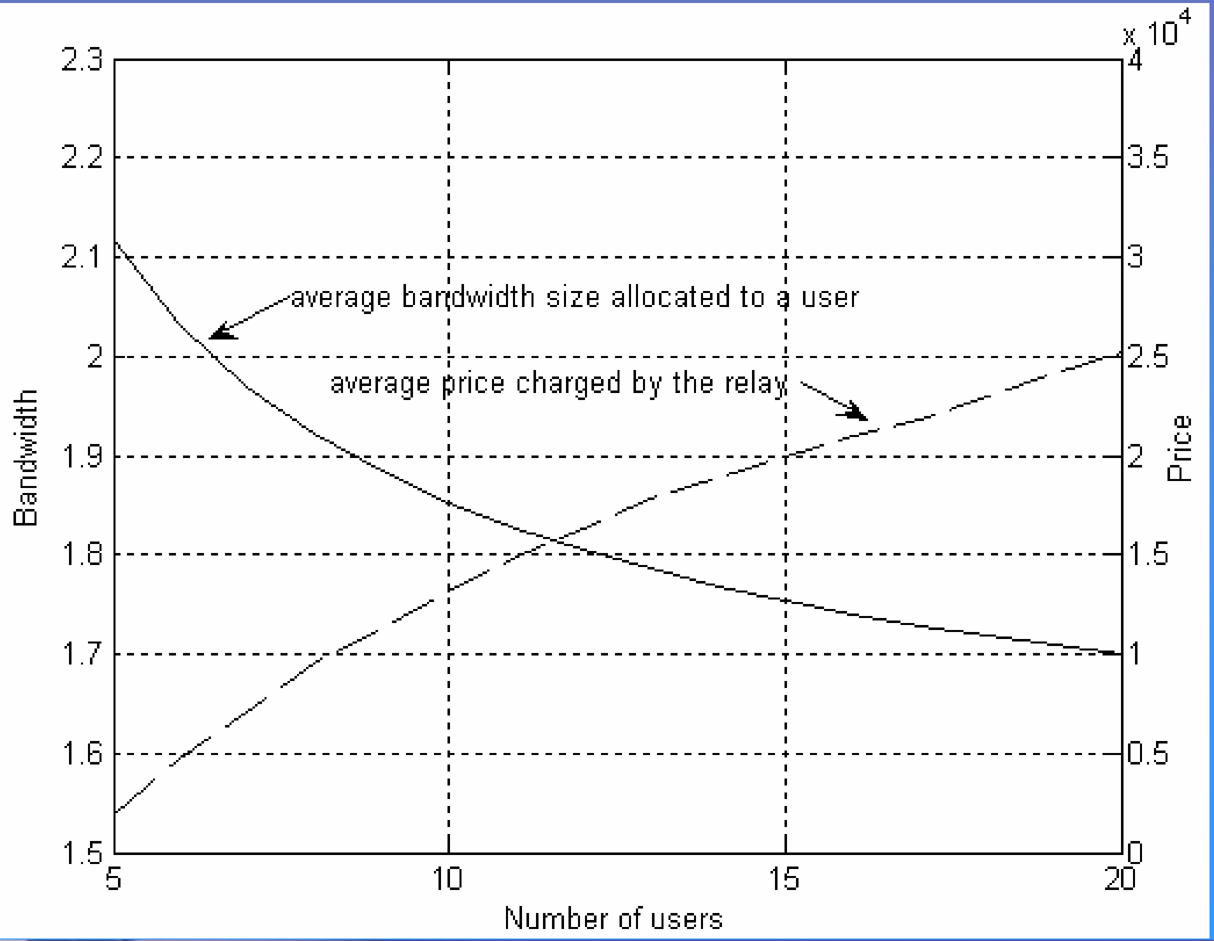
Delay


AODV-OLSR
AODV
average (in Wireless LAN.Delay (sec))
0.0010
0.0009
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
0m 0s
1m 0s
2m 0s
3m 0s
4m 0s
5m 0s

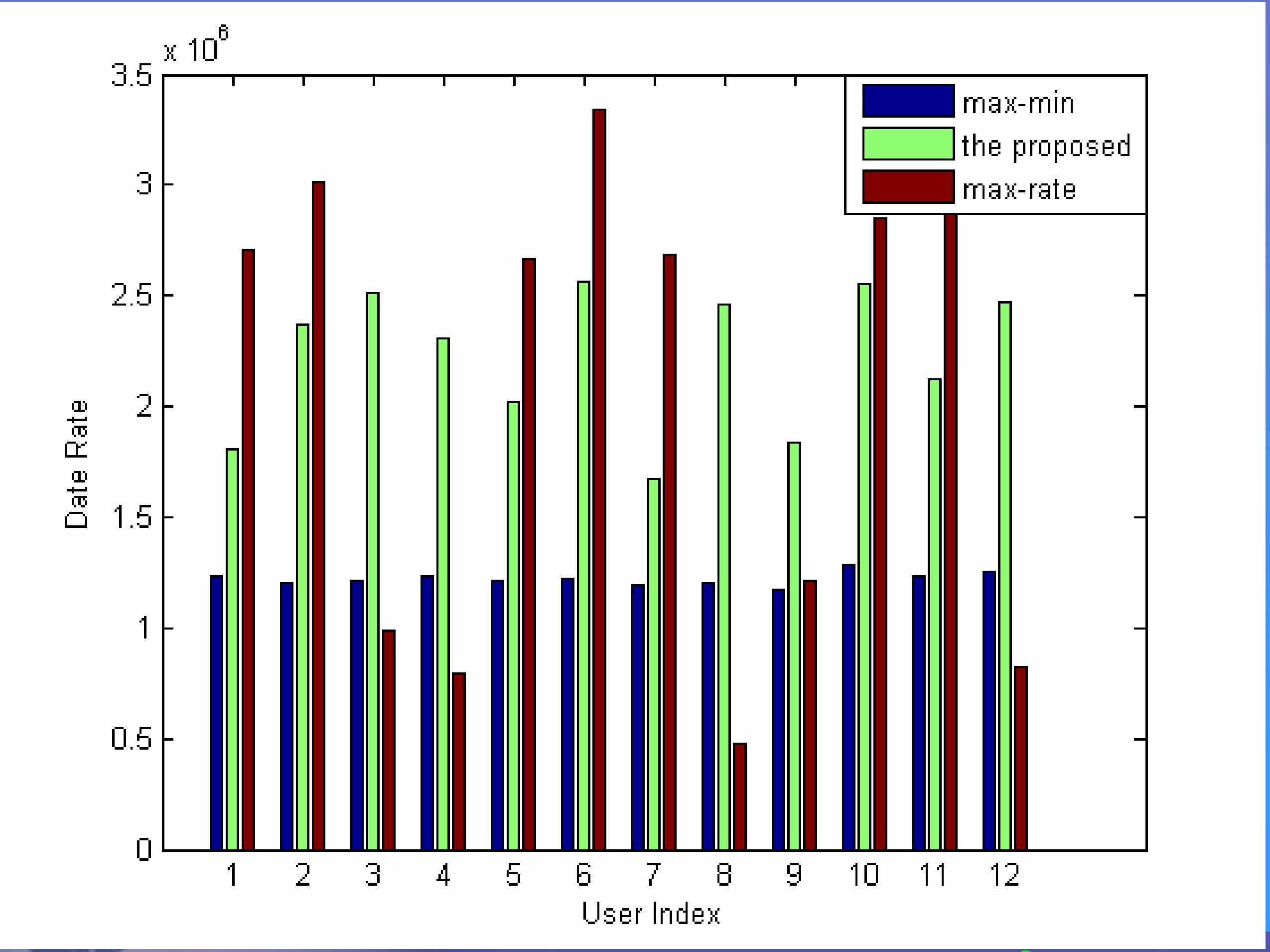
Joint Radio Resource Management Algorithms for Cooperative WMNs

- Why to cooperate?
  - Pricing-based cooperative transmission strategies is developed in order for selfish nodes to interact and cooperate with each other.
- How to cooperate?
  - As looking at the transmitting power as also a kind of resource, we developed joint resource allocation algorithms simultaneously in three dimensions, i.e., time, frequency and power domain.
  - We are developing joint radio resource management algorithms in five dimensions, i.e., time, frequency, code, space and power domain.

Resource vs. Price



Throughput vs. Fairness



- Introduction to our research team
- Broadband wireless access systems in near space
- Advanced MIMO detector
  - Hold partial ML algorithm
- Interpolation based precoding with limited feedback for MIMO-OFDM systems

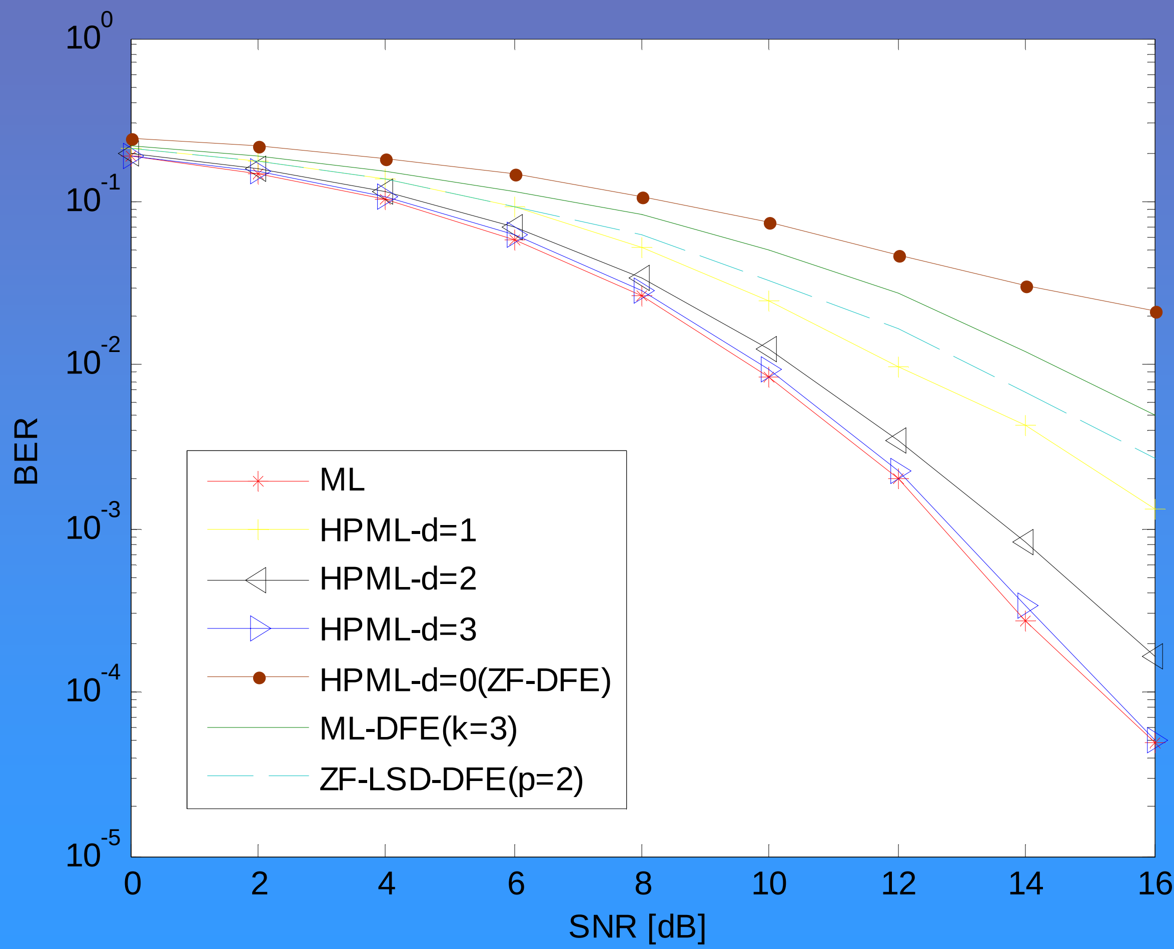
Background

- In a MIMO system, it is prefer to adopt the maximum likelihood **(ML)** detection to fully extract both multiplexing and diversity gain.
  - Although the classic full ML detection can obtain the optimal systematic performance, it has not been used in practice due to its extremely high complexity.
- Research focuses on some detecting algorithms with low complexity.
  - Linear detecting algorithms: ZF, MMSE
  - Non-linear detecting algorithms: ZF-DFE, ML-DFE, QR, SD

Advanced MIMO Detector

- Purpose
  - performance: approaching MLD performance
  - complexity: reduced and easy for accomplishing in engineering
- Hold Partial ML (HPML) algorithm
  - Firstly, select d columns of $\mathbf{H}$, whose MSEs are the largest ones.
  - Secondly, detect the residue M-d columns by ZF-DFE or MMSE-DFE to form one candidate for each M-layer signal vector.
  - Finally, detect the transmitted signals by using partial ML from the candidate set of combined M-layer signal vectors.
    - We could further reduce the complexity of the partial ML by using the above DFE information.

Performance



Complexity

	ML
MULT	$[N*M]\times[M*1]$: $(N_s)^M$ times
COM	$[N*1]$: $(N_s)^M-1$ times
D	no

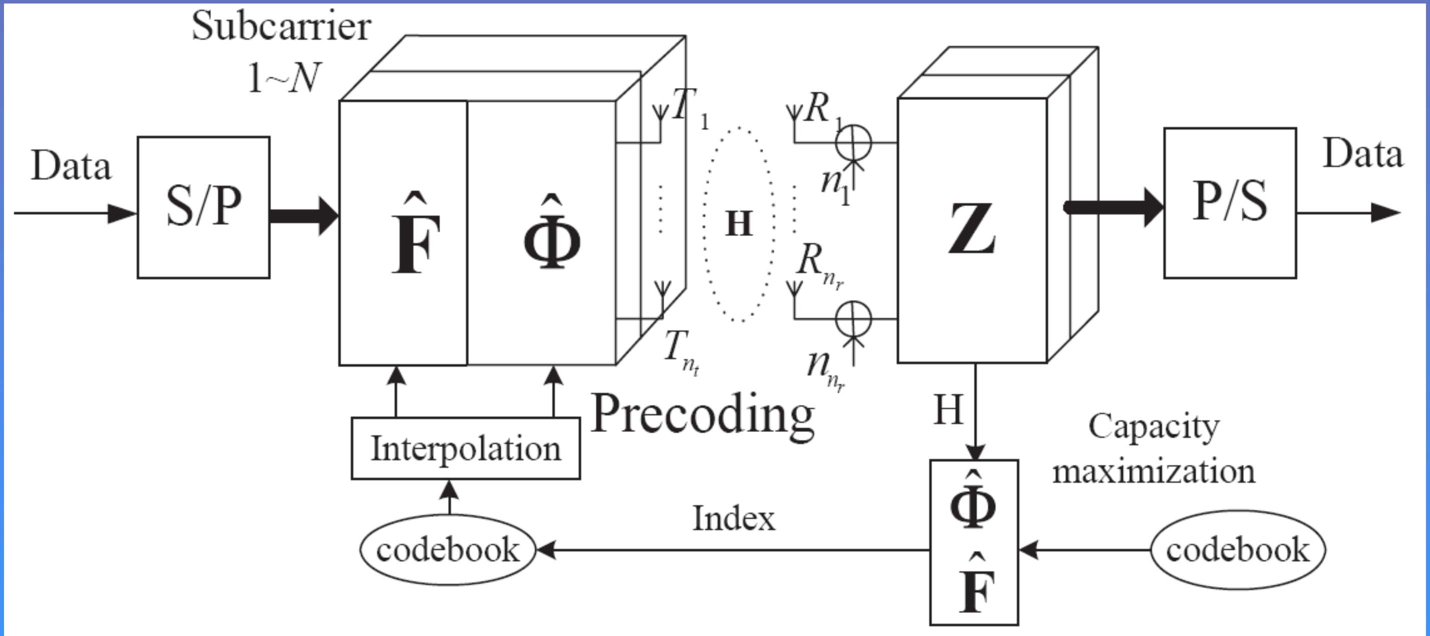
	HPML
MULT	$[N*d]\times[d*1]$: $(N_s)^d$ times $[1*N]\times[N*1]$: $[N*1]\times[1*1]$ $(M-d)\times(N_s)^d$ times
COM	$[N*1]$: $(N_s)^d-1$ times
D	$[1*1]$: $(M-d)\times(N_s)^d$ times

Conclusions

- When the selected number, i.e., d, is not relatively small, the performance of HPML is very approximate to that of ML detection, while its complexity is nearly the same as that of low dimension ML detection.

- Introduction to our research team
- Broadband wireless access systems in near space
- Advanced MIMO detector
  - Hold partial ML algorithm
- Interpolation based precoding with limited feedback for MIMO-OFDM systems

Block Diagram of a Limited Feedback Precoding MIMO-OFDM System



- If the channel is known to the transmitter, the capacity can be increased by resorting to the precoding algorithms.
- It is possible by various means, e.g., feedback, to learn the channel state information (CSI) at the transmitter. In this approach, CSI is obtained at the receiver and sent to the transmitter on the revise link.

Interpolation based Limited Feedback Precoding

- How to reduce the feedback data further?
  - In MIMO-OFDM systems, even if several bits are conveyed back for each subcarrier, the total feedback data is also huge since the number of subcarrier N is large in most cases.
  - We proposed an interpolation based limited feedback precoding (ILFP) scheme.
    - Precoding scheme
    - Interpolation strategy
    - Codebook design method

Precoding scheme

- N subcarriers are equally divided into M subcarrier clusters and $u = N/M$.
  - Subcarriers' channel responses in one cluster are dependent, so do their precoding matrices.
- Subcarriers in one cluster only needs one pair of precoding matrices which is determined at the receiver aiming at capacity maximization.

Interpolation strategy

- Through limited feedback, the transmitter obtains M pairs of precoding matrices. They will be recovered to N pairs by interpolation.
  - During interpolation, there is a phase rotation problem which is solved by phase quantization method.

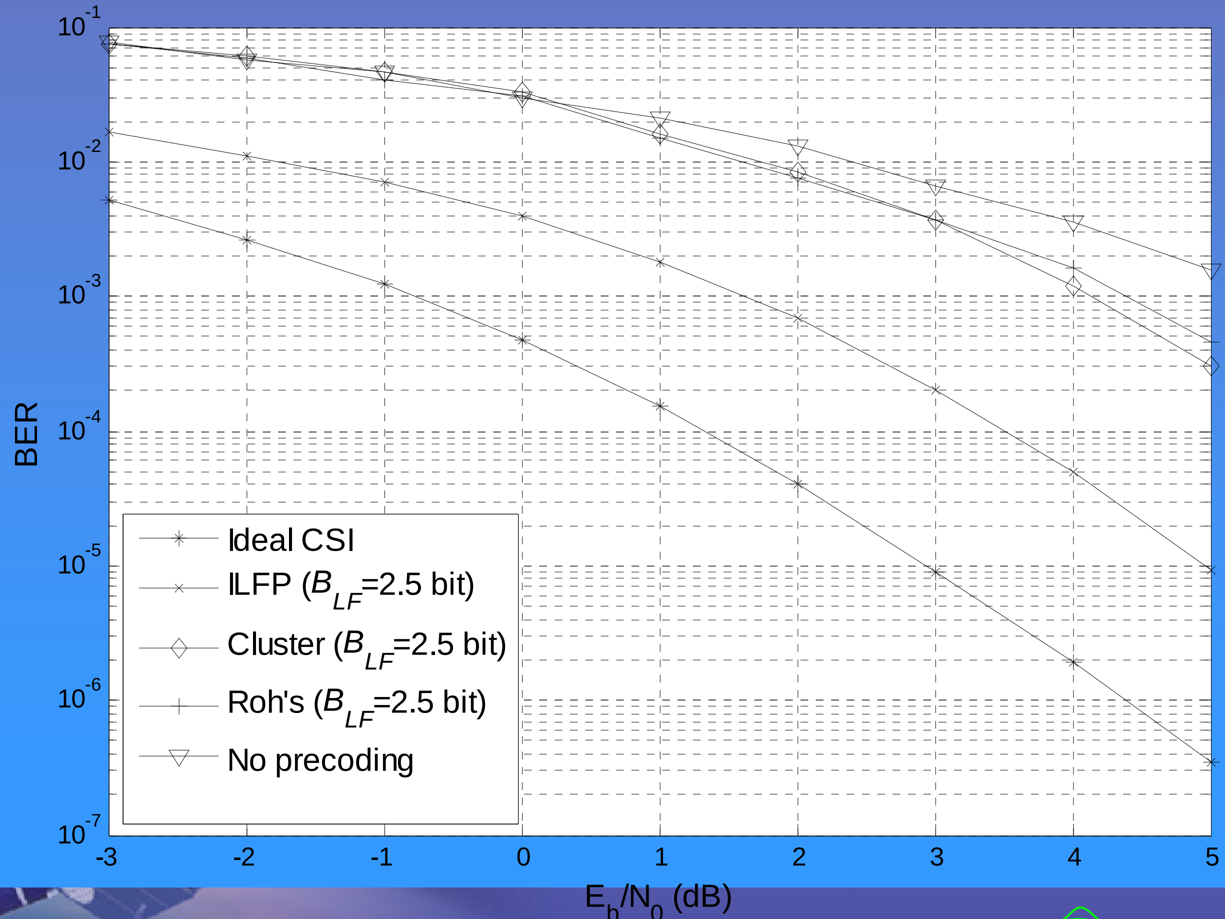
Codebook design method

- We use Lloyd algorithm to design the codebook *W*.
  - The capacity loss is used as the price function.
- If the scale of codebook *W* is *L*, the number of feedback bits needed per subcarrier is

$$B_{LF} = M\left(\log_2 L + \log_2 T\right)/N$$
$$= \left(\log_2 L + \log_2 T\right)/u$$

  - The feedback data is reduced by a factor of *u*.

BER performance (COST207-TU, 4bps/Hz)



Thank you very much for your kind attention!

Any question?

lqzhao@mail.xidian.edu.cn