Advanced Wireless Broadband Communications in Rural Areas

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Geographically Large
Diverse Population Density
Challenges for Universal Broadband Access
Why there should be a difference in target data rates between cities and rural areas?
Significant scientific and technical challenges to provide 100 Mb/s in rural areas by fixed wireless and satellite
Significant scientific and technical challenges to provide 100 Mb/s in rural areas by fixed wireless and satellite
12/1 Mb/s
12/1Mb/s
CSIRO’s WLAN Testbed

Carrier: 2.4 GHz, 5.2 GHz, 40 GHz

Bandwidth: 125 MHz

Time resolution: 8 ns raw, 16 ns after filtering.

BER / FER measurement
Basics of OFDM
Basics of OFDM
Basics of OFDM
Basics of OFDM

110100110

1 1 0
1 0 0
1 1 0
110100110

1 1 0
1 0 0
1 1 0
110100110
Basics of OFDM
United States Patent
O'Sullivan et al.

[54] WIRELESS LAN

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[73] Assignee: Commonwealth Scientific and Industrial Research Organisation, Australia

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[57] ABSTRACT
The present invention discloses a wireless LAN, a peer-to-peer wireless LAN, a wireless transceiver and a method of transmitting data, all of which are capable of operating at...
CSIRO’s 4x4 MIMO-OFDM Demonstrator

Multi channel transmitters

Multi channel receivers

World highest combination of data rate (600 Mb/s) and spectrum efficiency (15 b/s/Hz) in 2005
Basics of MIMO

\[ h_{ij} = \alpha_{ij} e^{j\theta_{ij}} \]

\[
\begin{bmatrix}
  r_1 \\
  r_2 \\
  \vdots \\
  r_{n_r}
\end{bmatrix}
= 
\begin{bmatrix}
  h_{11} & h_{12} & \cdots & h_{1n_t} \\
  h_{21} & h_{22} & \cdots & h_{2n_t} \\
  \vdots & \vdots & \ddots & \vdots \\
  h_{n_r1} & h_{n_r2} & \cdots & h_{n_rn_t}
\end{bmatrix}
\begin{bmatrix}
  x_1 \\
  x_2 \\
  \vdots \\
  x_{n_t}
\end{bmatrix}
+ 
\begin{bmatrix}
  n_1 \\
  n_2 \\
  \vdots \\
  n_{n_r}
\end{bmatrix}
\]

\[ r = Hx + n \]
Basics of MIMO ZF

\[ r = Hx + n \]

\[ z = Wr = x + Wn \quad W = (H^H H)^{-1} H^H \]

\[ \hat{x}_{iZF} = \arg \min_{\hat{x}_i \in Q} \left| z_i - \hat{x}_i \right| \]

Zero-Forcing Detection
Example of MIMO-OFDM Device
Each PC can only achieve up to $\frac{600}{4} = 150$ Mbps PHY
Multi-User MIMO

Each PC can achieve 150 Mbps PHY (Tx needs to know the channel)
Multiuser MIMO in Rural Area
Basics of MU-MIMO Uplink

$\mathbf{r} = \mathbf{H} \mathbf{x} + \mathbf{n}$
Basics of MU-MIMO Uplink ZF Detection

\[ \mathbf{r} = \mathbf{Hx} + \mathbf{n} \]

\[ \mathbf{z} = \mathbf{Wr} = \mathbf{x} + \mathbf{Wn} \quad \mathbf{W} = (\mathbf{H}^H\mathbf{H})^{-1} \mathbf{H}^H \]

\[ \hat{x}_{iZF} = \arg\min_{\hat{x}_i \in Q} |z_i - \hat{x}_i| \]
Basics of MU-MIMO Downlink

$$h_{ij} = \alpha_{ij} e^{j\theta_{ij}}$$

$$\begin{bmatrix}
    r_1 \\
    r_2 \\
    \vdots \\
    r_{n_r}
\end{bmatrix} = \begin{bmatrix}
    h_{11} & h_{12} & \cdots & h_{1n_t} \\
    h_{21} & h_{22} & \cdots & h_{2n_t} \\
    \vdots & \vdots & \ddots & \vdots \\
    h_{n_r1} & h_{n_r2} & \cdots & h_{n_rn_t}
\end{bmatrix}
\begin{bmatrix}
    x_1 \\
    x_2 \\
    \vdots \\
    x_{n_t}
\end{bmatrix} + \begin{bmatrix}
    n_1 \\
    n_2 \\
    \vdots \\
    n_{n_r}
\end{bmatrix}$$

$$\mathbf{r} = \mathbf{Hx} + \mathbf{n}$$
Basics of MU-MIMO Downlink ZF Precoding

\[ r = Hx' + n \]

\[ x' = \frac{1}{\beta} Wx \quad \text{HW} = I \]

\[ r = \frac{1}{\beta} x + n \]

\[ r' = \beta r = x + \beta n \]
1st Stage Ngara Access Demonstrator
1st Stage Ngara Access Demonstrator Parameters

- MU-MIMO-OFDM with 6 users and 12 access point antennas
- Carrier frequency: 641.5 MHz
- Operational bandwidth: 7 MHz
- Number of occupied sub-carriers: 1705
- Number of data sub-carriers: 1680
- Sub-carrier spacing: 8 MHz / 2048 ≈ 3.9 kHz
- OFDM symbol duration (without guard interval): 256 μs
- Cyclic prefix: 64 μs
- OFDM symbol modulation: 64 QAM
Six User MU-MIMO-OFDM Uplink in Rural Area, 20 bits/s/Hz

Fewer towers for CSIRO rural broadband wireless

Reference: 1125

In what could prove to be a major breakthrough for people living in rural and regional Australia, CSIRO is developing wireless broadband technology that could operate using barely a quarter the number of transmission towers required by current systems.

21 March 2011

"Analysis we've commissioned shows other wireless technologies, which typically operate at higher frequencies, would require four times as many towers," CSIRO ICT Centre Director Dr Jan Oppermann said.

CSIRO's first prototype Ngapa access system currently gives six simultaneous users 12 megabits per second (Mbps) from the network to their home and 12 Mbps from their home to the network. It is being shown to decision makers in industry and policy this week.

"We feel symmetry is important as people interact more using bandwidth-hungry applications such as video conferencing — they could be working from home, participating in a lesson or visiting their doctor online," CSIRO ICT Centre Director Dr Jan Oppermann said.

"It's easy to see how these services would be particularly valuable in rural areas."

CSIRO's Ngapa technology aims to bring wireless broadband access to people living beyond Australia's planned fibre network using existing broadcasting infrastructure and UHF spectrum, such that left behind when Australian TV goes 100 per cent digital.

"Even with the analog TV switch-off, there won't be much spectrum to spare so any wireless system has to be very efficient, sending as much information as possible within its allotted frequency range," Dr Oppermann said.

"We feel symmetry is important as people interact more using bandwidth-hungry applications such as video conferencing — they could be working from home, participating in a lesson or visiting their doctor online."

Dr Jan Oppermann, CSIRO
1st Stage Ngara Access Demonstrator Field Trial

ABC news clip
Access Point Antenna Array
MU-MIMO-OFDM Downlink Demonstrator
AP Antenna Array and Hardware Units
MU-MIMO-OFDM Downlink Demonstrator
UT Antenna
1st Stage Ngara Access
Real-Time Uplink / Downlink Demonstration
2nd Stage Ngara Access Demonstrator Parameters

- MU-MIMO-OFDM with 12 users and 24 access point antennas
- Carrier frequency: 638 MHz / 806 MHz
- Operational bandwidth: 14 MHz per downlink/uplink
- Number of occupied sub-carriers: 3456
- Number of data sub-carriers: 3348
- Sub-carrier spacing: 8 MHz / 2048 \(\approx 3.9\) kHz
- OFDM symbol duration (without guard interval): 256 \(\mu\)s
- Cyclic prefix: 64 \(\mu\)s
- OFDM symbol modulation: 64 QAM
2nd Stage Ngara Access Demonstrator Access Point
2nd Stage Ngara Access Demonstrator User Terminal
2nd Stage Ngara Access Demonstrator

- 18 user MU-MIMO-OFDM uplink and downlink using offline processing successful in laboratory environment, 67 bits/s/Hz spectrum efficiency.
- 14 user MU-MIMO-OFDM uplink using real-time signal processing successful in laboratory environment, 51 bits/s/Hz spectrum efficiency.
- Planned minimum 12 user MU-MIMO-OFDM uplink/downlink using real-time signal processing by mid July 2012.
Geographically Large
Diverse Population Density
Challenges for Universal Broadband Access
We have solutions
Acknowledgement

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Publications

- **Journal paper**

- **Technical report**
  - Smithton Field Trial (trial date Dec 2010, publication date Feb 2011) Technical Report

- **Patent application**
  - H. Suzuki, J. Pathikulangara, and D. Humphrey, “Multi-user MIMO-OFDM communication system,” Australian Application No 2010903932, September 2010
Publications