Wireless networking using conductive surfaces

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Existing wireless technologies

Ignore a large class of use cases
Devices often placed on common surface
Devices often placed on common surface

- Shelves
- Walls
Can we achieve high data rate communication when devices come in contact with a common surface?
Fundamental challenge

Common surface materials are not conductive

Wood

Sheetrock

Plastic
Our approach: conductive material
Our approach: conductive material

Materials can be used for wireless communication
Tiny contact point

8 mm
Tiny contact point

Do conductive surfaces propagate RF signals?

8 mm
Surface MIMO testbed

16 feet
Do conductive surfaces propagate RF signals?

![Graph showing power in dBm vs distance in feet for 900MHz, 2.4GHz, 5GHz frequencies.](image)
Do conductive surfaces propagate RF signals?

- Conductive surfaces significantly attenuate RF signals across different frequencies.
- The attenuation increases with distance, especially at higher frequencies (e.g., 5GHz).
- At no contact, the power level drops dramatically, indicating a significant loss in RF signal strength.

The chart shows the power (in dBm) as a function of distance (in feet) for 900MHz, 2.4GHz, and 5GHz frequencies. The data points indicate a strong correlation between distance and power, with a notable drop in power with increasing distance at all frequencies.
Do conductive surfaces propagate RF signals?

Communication is due to contact with the surface.
Effect of substrate

Signal Strength (dB)

900MHz  2.4GHz  5GHz

Paper  Plastic  Wood  Sheetrock
What happens with objects on the surface?

Without objects

With objects
What happens with objects on the surface?

Without objects

With objects
What happens with objects on the surface?

Noise on channel

Without objects

With objects
What happens with objects on the surface?

Noise on channel

Without objects

With objects
What happens with objects on the surface?

Noise on channel

Delay spread addressable with OFDM cyclic prefix
Does grounding matter?

With ground

Without ground
Two new ways to communicate using surfaces

MIMO for single-antenna devices

Gigabit communication
Traditional MIMO

Transmitter

Receivers
Traditional MIMO

Transmitter

Receivers
Exploit surface as additional spatial path
Surface MIMO
Surface MIMO
Traditional MIMO system

\[ \lambda/2 \]

6.25 cm
Traditional MIMO system

Too large for a mobile device
Traditional MIMO system

Streams become too correlated
Surface MIMO contact separation

Achieves MIMO with 1 cm separation
Propagation on surface is slower than over the air

Surface channel creates additional spatial path
How well does Surface MIMO work in practice?

1. Over the air 1x1 system
2. Over the air MIMO system
3. Surface MIMO without objects
4. Surface MIMO with objects
Throughput gains

Throughput (Mbps)

Distance (feet)

Over the air 1x1
Throughput gains

Throughput (Mbps)

Distance (feet)

Over the air 1x1

Over the air MIMO ($\lambda/2$ separation)
Throughput gains

Throughput (Mbps) vs. Distance (feet)

- Over the air 1x1
- Over the air MIMO ($\lambda/2$ separation)
- Surface MIMO without objects
Why are we better than traditional MIMO?

1. Surface acts like an antenna
2. Multi path on surface is stronger than multi path over the air
Cluttered Surface MIMO testbed
Throughput gains

Throughput (Mbps)

Distance (feet)

Over the air 1x1

Over the air MIMO (\(\lambda/2\) separation)

Surface MIMO without objects

Surface MIMO with objects
## Throughput gains

<table>
<thead>
<tr>
<th>Over the air 1x1</th>
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# Throughput gains

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Contact separation

![Graph showing throughput (Mbps) versus distance (feet) with contact separation distances of 6cm, 3cm, and 1cm.](image)
Channel state information

Signal strength (dB)

Subcarrier index

Rx1-Tx1
Rx2-Tx1
Channel state information

Signal strength (dB) vs. Subcarrier index for different transmission pairs:
- Rx1-Tx1
- Rx1-Tx2
- Rx2-Tx1
- Rx2-Tx2

Comparison at 1 feet and 16 feet distances:
- 1 feet: Signal strength remains relatively stable.
- 16 feet: Signal strength shows more variation over the subcarrier index.
Received signal strength

![Graph showing the received signal strength (RSSI) in dB versus distance in feet for different MIMO configurations: Baseline MIMO, Spraypaint MIMO, and Cloth MIMO.]
Two new ways to communicate using surfaces

MIMO for single-antenna devices

Gigabit communication
Gigabit surface communication
Gigabit surface communication
Stitching together ISM bands

902 - 922 MHz

2.402 - 2.472 GHz

5.17 - 5.25 GHz

5.735 - 5.815 GHz
Does the surface interfere with on air signals?

1. Around a monopole antenna
2. In front of the spray painted surface
3. Behind the spray painted surface
Does the surface interfere with on air signals?

- Power (dBm)

-20
-30
-40
-50
-60

Around monopole antenna: -30 dBm
Front of spraypainted surface: -30 dBm
Back of spraypainted surface: -30 dBm
Does the surface interfere with on-air signals?

- Around monopole antenna: 
  - Back of spraypainted surface: -30 dB
  - Front of spraypainted surface: -43 dB

The difference in power is 13 dB.

The graph shows a comparison of power levels around and on the surface, indicating interference levels.

Power (dBm)
-60 -50 -40 -30 -20 -10 0 10
Does the surface interfere with on air signals?

Less over the air interference
What capacity can we achieve?

Link rates of 776 Mbps - 1.27 Gbps
Can we share the surface?

**Same channels**

- **One flow**
  - Client 1: 50 Mbps
  - Client 2: 40 Mbps

- **Two flows**
  - Client 1: 30 Mbps
  - Client 2: 20 Mbps

**Different channels**

- **One flow**
  - Client 1: 40 Mbps
  - Client 2: 30 Mbps

- **Two flows**
  - Client 1: 20 Mbps
  - Client 2: 10 Mbps
Conclusion

- Detailed *characterization* of conductive paint and cloth for communication
- Enable **MIMO communication** between small devices via conductive surfaces
- First communication design to support **Gbps data rates** over surfaces