The Impact of Correlated Blocking on Millimeter-Wave Personal Networks

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PANs, Wearables, and Virtual Reality

- Multiple devices in and around human body
  - Low-rate fitness monitors to high-rate virtual reality devices.
  - Such devices arranged into personal-area networks (PANs).
  - Military applications include training (VR) and situational awareness (AR).
- Critical challenge
  - Supporting Gbps per user in dense environments.
  - Effective operation in confined areas like VR rooms, ships, aircraft.

[1] Photo by David Paul Morris/Bloomberg via Getty Images
High bandwidth and reasonable isolation

Compact antenna arrays to provide array gains via beamforming

Commercial products already available: IEEE 802.11ad, WirelessHD

1 47 CFR 15.255; 2 ARIB STD-T69, ARIB STD-T74; 3 Radiocommunications Class License 2000; 4 CEPT : Official journal of the EU;
Challenges and Opportunities of mmWave for D2D

- **Antenna Directivity**
  - To compensate for path-loss, mmWave antennas are directional.
  - Can model as sectorized antenna.
  - Interference tends to be “pointy”.

- **Blockage**
  - mmWave subject to blocking.
  - Propagation primarily LOS.
  - At mmwave, human bodies are a main source of blockage.
  - Blockage isolates interference.
Modeling Blockage

- Blockage can be modeled as a point process.
  - Here, a binomial point process.
- Here, each source of blockage represented by a blue circle.
  - Constant width “W”
  - Its shadow is shown
- Transmitters are:
  - If in shadow = blocked/NLOS
  - Otherwise LOS
Correlated Blockage

- Previous work has assumed that blocking is independent.
- However, blocking can be correlated.
  - One object could block more than one interferer
  - Correlation arises even if the blockage process is independent
- Goal of this paper is to characterize the impact of correlated blocking.
Computing Blockage Probability

- An interferer at distance $r$ from the receiver will be blocked if a blocking object lies in its blocking zone.
- Probability that a given object lies in a given blocking zone can be found using geometric arguments:

\[
p_z(r) = \frac{\text{Zone Area}}{\text{Network Area}}
\]

- If there are $K$ objects in the network, then the interferer is blocked if any of them are in its blocking zone:

\[
p_b(r) = 1 - (1 - p_z(r))^K
\]
Blockage Probability (An Example)

- Network topology
  - Radius-6 disc
  - $A = 6^2 \pi$
- Blockages
  - $W = 1$ or $2$
  - $K = 1$, $5$, or $20$
Outage Probability

- Assuming that LOS paths are AWGN and NLOS paths are completely attenuated, the SINR at the receiver is:

\[
\text{SINR} = \frac{1}{\text{SNR}^{-1} + \sum_{i=1}^{2} (1 - B_i) \left( \frac{R_i}{R_o} \right)^{-\alpha}}
\]

- An outage occurs whenever SINR < \(\beta\)
- The outage probability is the CDF of the SINR:

\[
F_{\text{SINR}}(\beta) = P[\text{SINR} \leq \beta]
\]

- The CDF depends on the statistics of \((B_1, B_2)\), which is a pair of correlated Bernoulli random variables with correlation coefficient \(\rho\).
How Blocking Correlation Impacts Outage

- **Example:**
  - 2 interferers at same distance
    - $R_1 = R_2 = 5$
  - $p_b(r) = 0.6$, corresponding to $W=1$, $K = 20$, $A=6^2\pi$, $r = 5$.
  - SNR = 15 dB and $\alpha = 2$.

- **Variable correlation coefficient $\rho$**
  - $\rho$ varies in increments of 0.1

- **SINR values:**
  - 9.5 dB = **both** interferers LOS
  - 11.4 dB = **one** LOS (one blocked)
  - 15 dB = **zero** LOS (both blocked)
The probability that both interferers are LOS (not blocked) is:

\[ p_{B_1,B_2}(0,0) = \left(1 - \frac{a_1 + a_2 - v}{A}\right)^K \]

The correlation coefficient is:

\[ \rho = \frac{p_{B_1,B_2}(0,0) - q_1q_2}{\sqrt{p_1p_2q_1q_2}} \]

- \( q_i = 1 - p_i \)
- \( p_i = p_b(R_i) \)
- \( i = \{1, 2\} \)

\( v \) = Intersecting area
The Correlation Coefficient

- $\rho$ depends on the angular separation $\theta$ between the interferers.
- Example network:
  - $R_1 = R_2 = 5$
  - $A = 6^2 \pi$

- Variable blockage width $W$
- Variable number of interferers $K$.
- Simulation shown by dots.
Outage vs. $\beta$

- CDF of the SINR
- Network:
  - $R_1 = R_2 = 5$
  - $\theta = 25^\circ$
  - $A = 6^2 \pi$
  - SNR = 15 dB and $\alpha = 2$
  - Variable $K$ & $W$
- Comparison:
  - Considering the correlation (solid blue line)
  - Ignoring the correlation (dashed red line)
  - Gap = $\rho pq$

Solid line accounts for correlation
Dashed line assumes $\rho = 0$
Outage vs. $\theta$

- Outage vs. angular separation
- Network:
  - $R_1 = R_2 = 5$
  - Variable $\theta$
  - $A = 6^2\pi$
  - $\text{SNR} = 15 \text{ dB and } \alpha = 2$
  - Variable $K$ & $W$
- Outage at two thresholds:
  - $\beta = 10 \text{ dB (both LOS)}$
  - $\beta = 13 \text{ dB (at least one LOS)}$
- Curves account for correlation
Antenna Directivity

- Previous results assumed the use of omnidirectional antennas.
  - mmWave systems typically employ directional antennas to overcome path loss.
- Here, we consider a 4-element antenna.
  - Each interferer points in random direction.
  - Both actual and sectorized approximation considered.
- Key parameters:
  - $K=5, W=2$
  - $R_1 = 4, R_2 = 5, \theta = 25^\circ$
Randomly Located Interferers

- In previous slides, interferers are in fixed locations.
- Here, we vary their location by drawing them from a BPP
  - Binominal point process
  - Independently and uniformly placed on the radius-6 circle
- Assumes 4-element antenna array
- Spatial averaging done via MC simulation.
  - Each trial corresponds to one network realization
  - 1000 trials
Concluding Remarks

-blocking may be correlated, even when the blockages themselves are independently placed.
  - Correlation more pronounced when there are only a few blockages or when the blockages are large.
  - The outage probability is more accurately computed if it accounts for blockage correlation.

- Outage also depends on antenna directivity.
  - Antenna patterns need to be taken into account.

- Future work:
  - Considering more than 2 interferers.
  - More sophisticated channel models: Fading, reflection, variable path loss.
  - Analytical approach to handling randomly located interferers.
QUESTIONS?