Cross-Layer control of Dense, Mobile, Millimeter-wave Networks
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Motivations & challenges
- < 6GHz spectrum crunch problem
- mm-wave bands
- Unique propagation conditions
- LOS, blockage
- Highly directional transmissions
- Mobility & density of future wireless systems demand flexible architectures

Expected outcomes
- A principled SDN framework with layer 1 & 2 radio abstractions, including proof-of-concept implementation
- Multi-Layer Radio Environment Map (ML-REM) that includes propagation and CSI layer, user location & mobility layer, & aggregate interference layer
- A programmable architecture that enables the real-time control and close coordination of mm-wave communications networks

ML-REM
- Maintaining beam alignment can be challenging
  - Huge overhead
  - Energy/bandwidth cost
  - “Patterns” can be learned & exploited to reduce overhead
- ML-REM provides situational awareness
  - Side information to reduce the cost of beam alignment by exploiting learned channel/mobility/interference patterns

Mm-wave in mobile, dense environments
- Need to keep track of mobile users
- Interference can be severe in dense environments
- Communication overhead overwhelming
- Highly flexible architecture needed for real-time control to cope with fast-varying network conditions; cross-layer design to reduce communication overhead

Goal & approach
- Goal: develop a framework to support mobility in high-density mm-wave communication networks
- Approach:
  - Employ the principles of software-defined networking (SDN) for design of flexible cloud-based mm-wave architectures
  - Develop a framework to learn “patterns” of the environment (mobility, channel, interference)
  - Exploit information from the environment database to adjust to changing conditions & reduce control overhead

Architecture
- Propagation and CSI layer
- User location and mobility layer
- Aggregate interference layer

SDN framework
- Network level adaptation via SDN interfaces
- Challenges:
  - Principled SDN support for mm-wave networks
  - Identification of wireless abstractions to enable easy programmability, fine-grained network control & quick reconfigurability

Initial access problem
- with Muddassar Hussain (PhD student)
- Problem: align tx/rx beams with mobile users
- Challenges:
  - Time & power constraints
  - How to optimally allocate resources between sensing & comm.?
- Goal: Design beam power, angle & width \((P, \phi, \omega)\) to optimize trade-off

Protocol
- BS sends beacons with parameters \((P_k, \phi_k, \omega_k)\), controlled in real-time
- If mobile user is within beam coverage region, it detects beacon & sends ACK
- BS refines position estimate
- Once desired accuracy achieved, data communication begins

MDP formulation
- MDP to jointly optimize sensing & comm.
- \(P_{\text{left}, k}\): remaining power budget
- \(U_k\): angle of uncertainty
- \(C()\): capacity
- \(V(U_k, P_{\text{left}, k}) = \max\{(N-k)C(P_{\text{left}, k}), (T-k)U_k\}\)
- \(\max_{P_k, \phi_k, \omega_k} E[V(U_{k+1}, P_{\text{left}, k}, P_k, \phi_k, \omega_k)]\)

Results
- Tradeoff over multiple dimensions:
  - Time: for beam alignment vs data comm.
  - Narrower beams require longer sensing time & yield higher capacity, BUT less time available for communication
  - Power: must be split optimally between sensing & comm.

Summary
- Future mobile & dense networks demand a high level of flexibility
  - We propose a flexible architecture for dynamic network control via SDN
  - We leverage situational awareness to reduce beam alignment cost via ML-REM
  - We employ a cross-layer perspective to jointly optimize sensing & data communication to reduce communication overhead


Traffic...