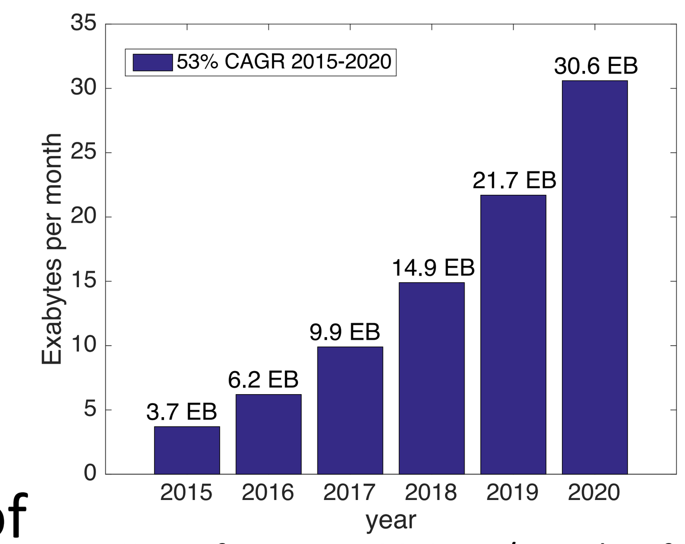
Cross-Layer control of Dense, Mobile, Millimeter-wave Networks

Nicolò Michelusi, Assistant Professor, *michelus@purdue.edu*

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



Cisco forecasts 30.6 EB/month of mobile data traffic by 2020. *Source: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2015-2020*

1

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

2

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

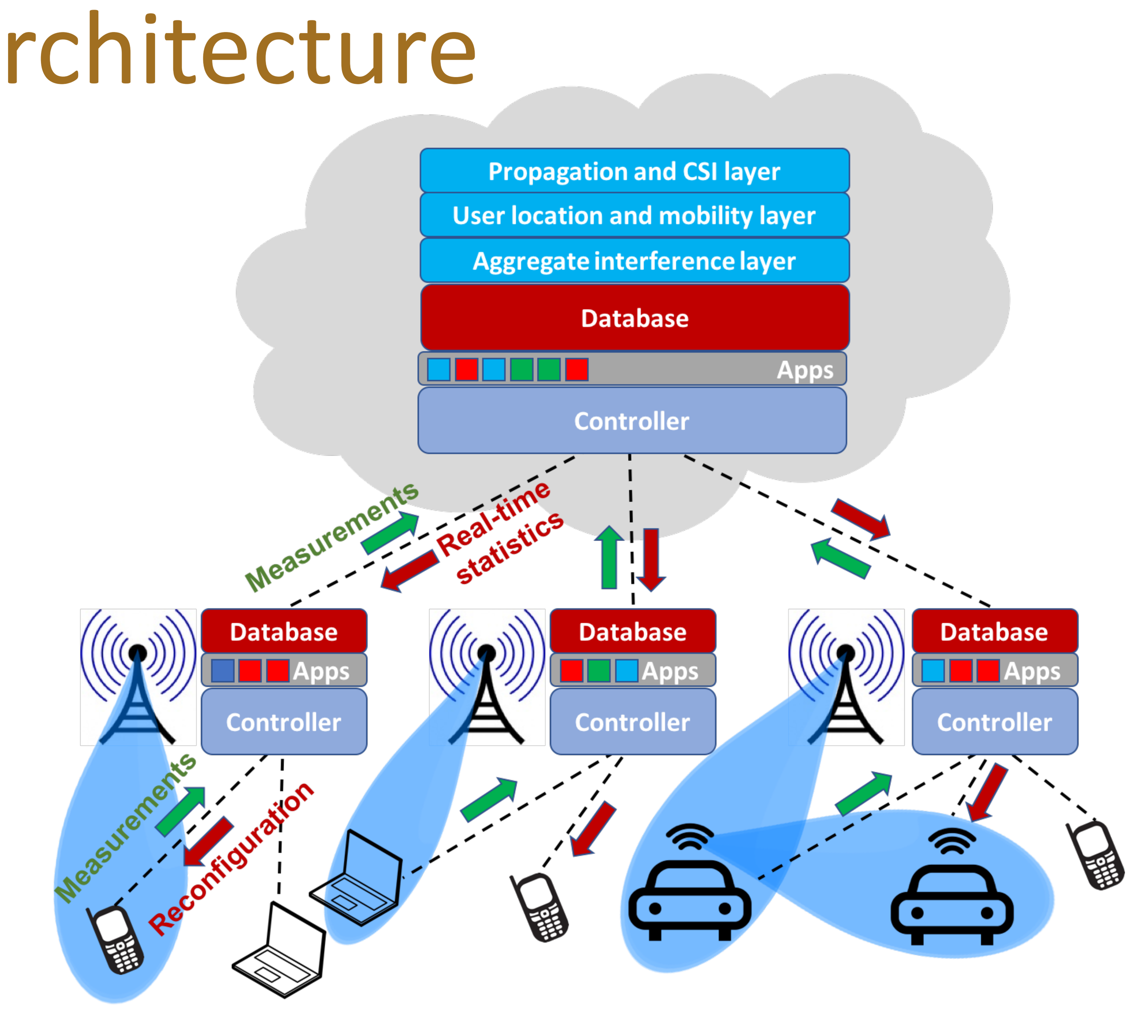
3

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

4

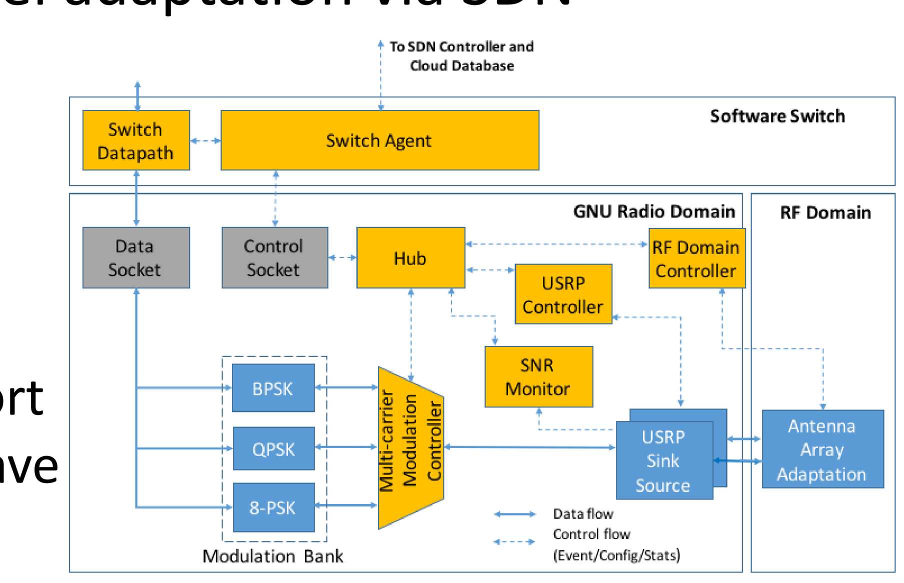
Architecture



5

SDN framework

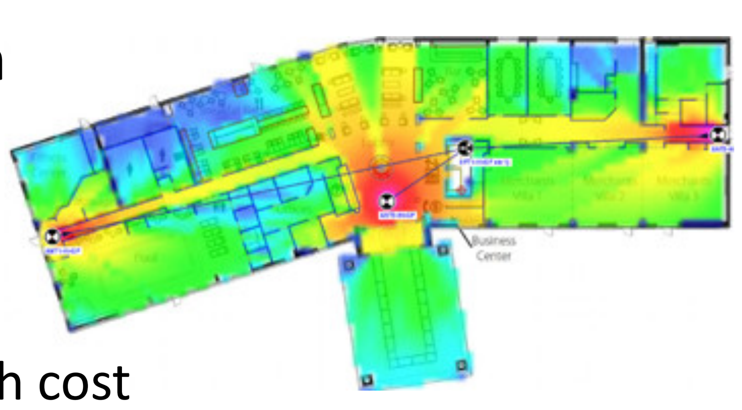
- Network level adaptation via SDN interfaces
- Challenges:
  - Principled SDN support for mm-wave networks
  - Identification of wireless abstractions to enable *easy* programmability, *fine-grained* network control & *quick* reconfigurability



6

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

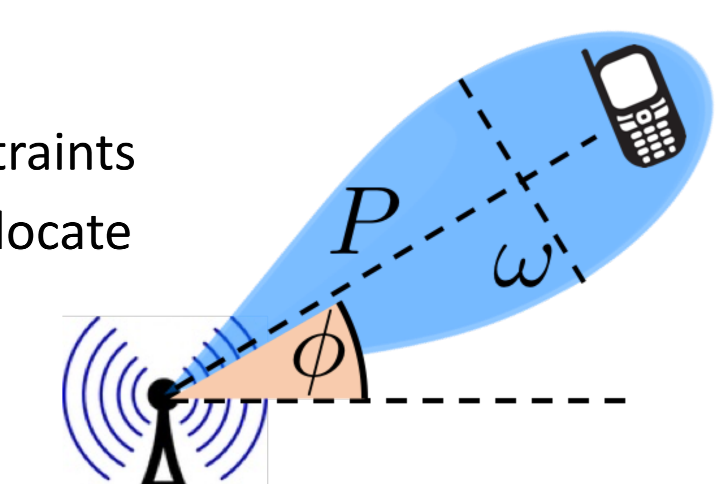


7

Initial access problem

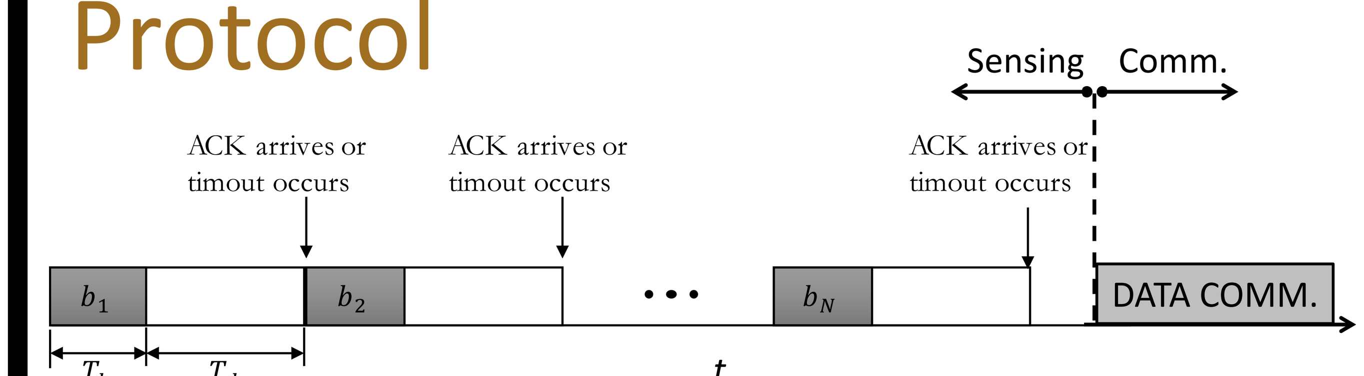
with Muddassar Hussain (PhD student)

- 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, ϕ, ω) to optimize trade-off



8

Protocol

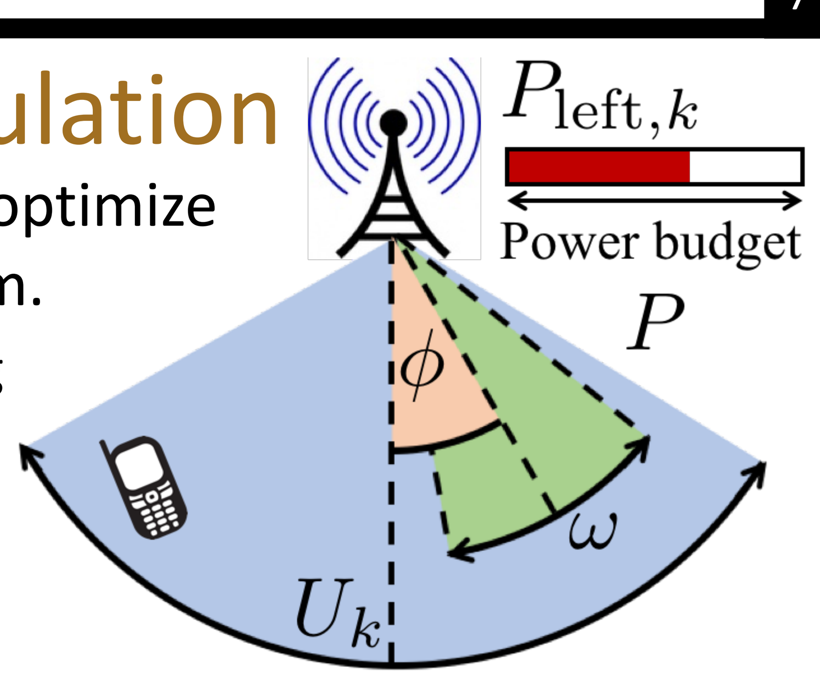


- BS sends beacons with parameters (P_k, ϕ_k, ω_k), controlled in real-time
- If mobile user is within beam coverage region, it detects beacon & sends ACK
- BS refines position estimate
- Once desired accuracy achieved, data communication begins

9

MDP formulation

- MDP to jointly optimize sensing & comm.
  - $P_{\text{left},k}$: remaining power budget
  - U_k: angle of uncertainty
  - $C(.)$: capacity



Data comm.

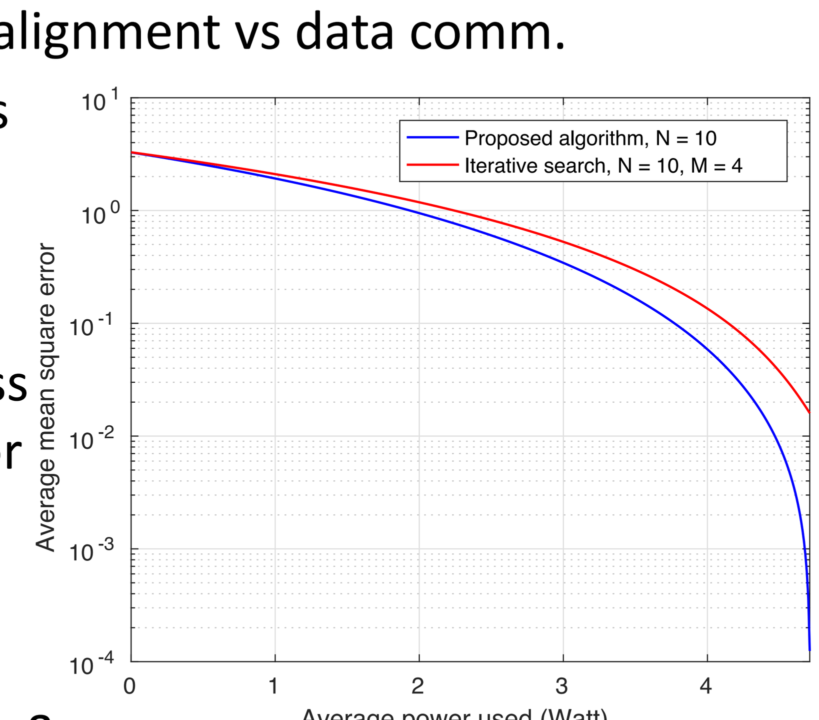
$$V(U_k, P_{\text{left},k}) = \max\left\{(N-k)C\left(\frac{P_{\text{left},k}}{(T-k)U_k}\right),\ \max_{P_k,\phi_k,\omega_k} \mathbb{E}\left[V(U_{k+1}, P_{\text{left},k} - P_k) \mid P_k, \phi_k, \omega_k\right]\right\}$$

Sensing

10

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.



11

Summary

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

NSF funded project: NSF EARS CNS-1642982: "*Real-time Control of Dense, Mobile, Millimeter Wave Networks Using a Programmable Architecture*" (2016-2019), Nicolò Michelusi (PI), David Love (co-PI), James Krogmeier (co-PI), *Purdue University*; Alex Sprintson (co-PI), *TAMU*; Chris Anderson (co-PI), *USNA*

12