mmWave Wireless Backhaul Scheduling of Stochastic Packet Arrivals

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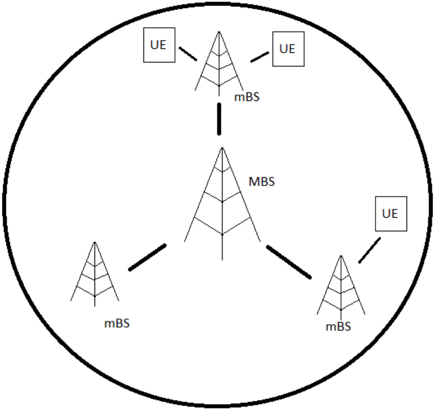
Motivation



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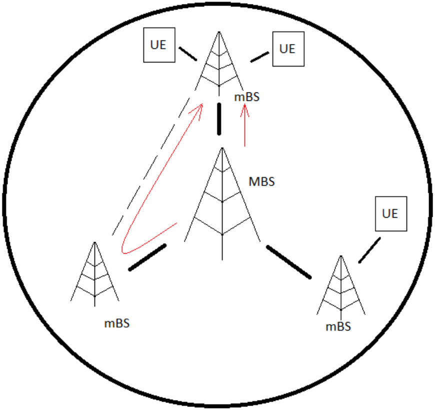

Network model

- 1 Macro Base Station (MBS).
- n Micro Base Stations (mBSs).
- Links from MBS to each mBS and from each mBS to every other mBS.
- Time slots, global clock.

Packet arrivals

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- Expected λ_i packets per round with destination i (e.g. according to Poisson process).

Packet transmissions

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- Up to k links from MBS active.
- Up to 1 link incident with a mBS active.
- Data may be relayed at most once.

Stochastic stability

Definition

A mmWBS algorithm is *stochastically stable* against arrival rates λ, if the expected number of rounds to return to a constant-sized queue is finite.

Related works

- 5G PPP Architecture Working Group, "View on 5G Architecture, version 1.0," Jul. 2016
- T. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G. Wong, J. Schulz, M. Samimi, and F. Gutierrez, "Millimeter wave mobile communications for 5G cellular: It will work!" IEEE Access, May 2013
- L. Tassiulas and A. Ephremides, "Stability properties of constrained queueing systems and scheduling policies for maximum throughput in multihop radio networks," Transactions on Automatic Control, 1992

Our contributions

- Consider mBS as relays to other mBS.
- Show that for “bad” arrival rates no algorithm can be stochastically stable.
- Prove stochastic stability of MaxWeight algorithm for “good” arrival rates.
- Develop a distributed implementation of MaxWeight algorithm that is stochastically stable for “good” arrival rates.

Configurations

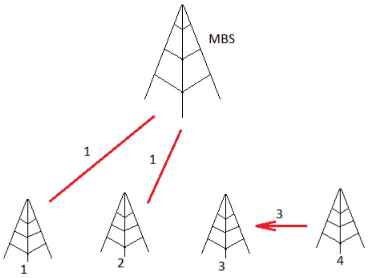
Definition

A configuration N is a vector that for every link (u, v) denotes which packets (i.e., which destination) are to be transmitted (if any).

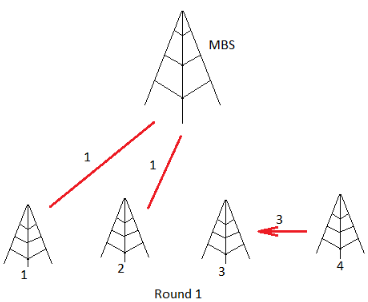
Definition

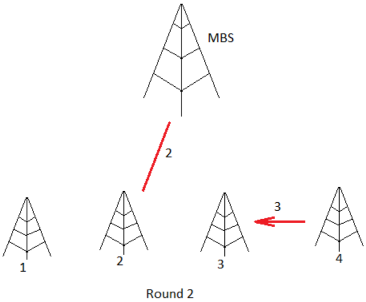
A configuration N is feasible if each mBS has only one incident edge active and there are at most k edges from MBS active.

Configurations



Flow vector





Stable flow vector

Definition

A flow vector f is stable, if:

- it is a linear combination of feasible configurations multiplied by link capacities and
- for each destination d flow outgoing from MBS equals to flow incoming to mBS d, which equals arrival rate λ_d.

Intuition: A stable flow vector f denotes how many packets are transferred over each link per round in a stable execution.

Bad arrival rates

Definition

An arrival-rate vector λ is *bad*, if for every combination of feasible configurations x, and every stable flow vector f, the following holds:

$$c_{i,j}^{-1} \cdot \sum_{d} f_{i,j,d} > x_{i,j} \quad \text{for some } x_{i,j} > 0 \ .$$

Good arrival rates

Definition

An arrival-rate vector λ is *good*, if there exists combination of feasible configurations x, and exists stable flow vector f, such that the following holds:

$$c_{i,j}^{-1} \cdot \sum_{d} f_{i,j,d} < x_{i,j} \quad \text{for all } x_{i,j} > 0 \ .$$

MaxWeight algorithm

At each time step MaxWeight chooses a feasible configuration N' such that $N' \leftarrow \arg\max_{N \in \mathcal{S}} \sum_{i,j,d} D_{i,j,d} N_{i,j,d}$, where

- $D_{i,j,d} = [Q_{i,d} - Q_{j,d}]\, c_{i,j}$ if $j \neq i$ and $D_{i,j,d} = Q_{i,d} c_{i,j}$ otherwise
- $\mathcal{S}$ – set of feasible configurations

Analysis idea

- Build a Markov chain $(Q(t))$, where $Q(t)$ denotes a vector of queue sizes $Q_{i,d}(t)$ at each node i of each destination d.

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- Use flows to show that for good arrival rates the drift is negative for almost all starting states q.

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- Use flows to show that for good arrival rates the drift is negative for almost all starting states q.
- Use Foster-Lyapunov Theorem to show that some states with small queues are positive recurrent.

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- The chosen configuration is used for the next L rounds.

Conclusion and Future Work

- We have developed an (almost) optimal distributed algorithm for mmWave Wireless Backhaul Scheduling that utilizes relays.
- Open future directions:
  - dynamic link capacities,
  - adversarial packet arrivals,
  - cost of activating/deactivating links.