Dynamic Resource Allocation for Efficient Wireless Packet Data Communcations

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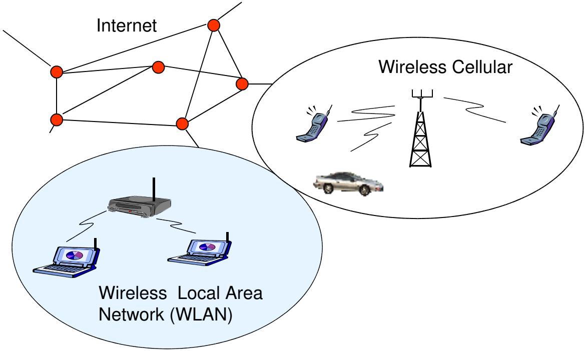
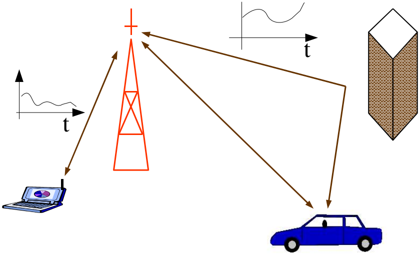
Broadband Wireless



- Demand for mobile wireless internet access
- Need support for multimedia data transfer

Broadband Wireless: Challenges

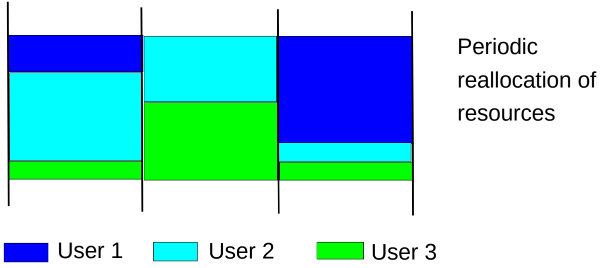


- High data rates and limited/expensive spectrum
  $\Rightarrow$ need high spectral efficiency
- Shared resources and multiple access
- Multipath fading channel
- Bursty traffic characteristics

Broadband Wireless: Some Proposals

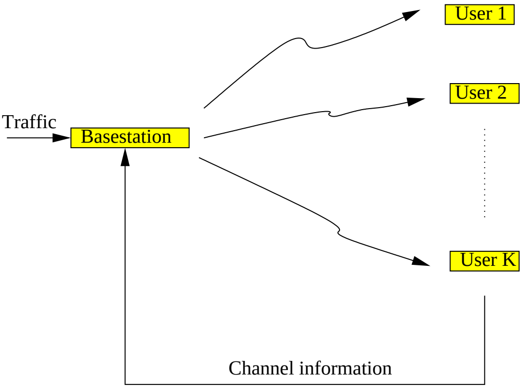
- Code-Division Multiple Access (CDMA)-based
  - 1xEV-DO (HDR)
  - HSDPA
  - 1xEV-DV
- Orthogonal Frequency Division Multiplexing (OFDM)-based:
  - FlashOFDM
  - IEEE 802.16e
  - IEEE 802.20

Key Techniques



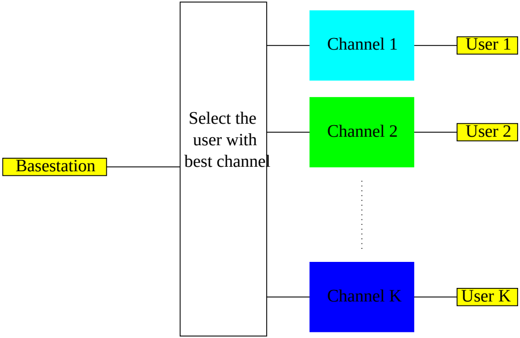
- Adaptation to channel and traffic conditions
- Dynamic resource allocation
  - Reallocation period of the order of a few milliseconds

Downlink Resource Allocation Problem



- Physical resources: power and bandwidth
- Maximize system throughput
- Total transmit power constraint
- Fairness or Quality of Service (QoS) constraints

Maximizing Capacity



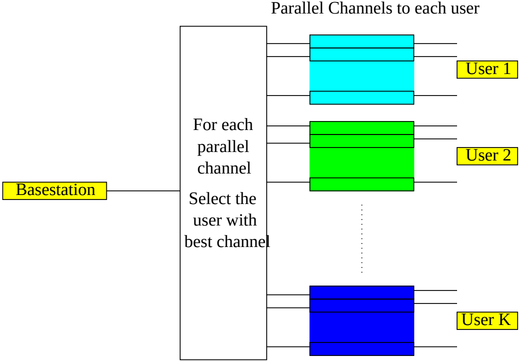
- All power and bandwidth resources to one user
- User with best achievable rate chosen:

$$i = \arg\max_k R_k,$$

where R_k is the rate that can be supported by user k.

- No fairness or QoS constraint

Maximizing Capacity: Parallel Channels



- Bandwidth resources split to achieve parallel channels
- For each channel n, user with best channel conditions chosen:

$$i_n = \arg\max_k R_{k,n}.$$

- Water-filling power allocation
- No fairness or QoS constraint

Fairness and Quality of Service (QoS)

- Various notions of fairness or QoS
- Round-Robin
- Proportional Fairness [Tse02]

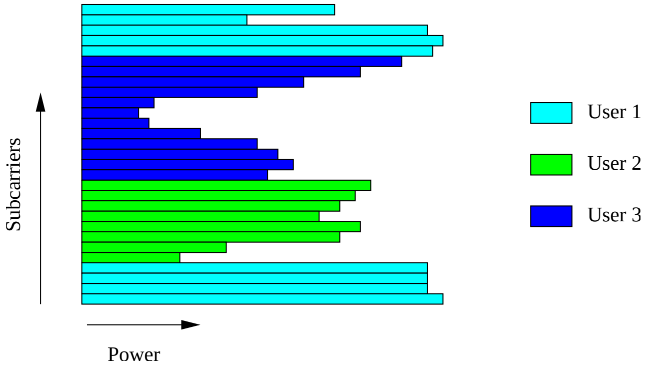
$$i = \arg\max_k \frac{R_k}{R_{k,av}},$$

  where $R_{k,av}$ is the average rate that can be supported by user k.
- Modified-Largest Weighted Delay First (M-LWDF) [Andrews00]

$$i = \arg\max_k \gamma_k W_k R_k,$$

  where W_k is the Head-Of-Line (HOL) packet delay for user k, and $\gamma_k = \frac{C_k}{R_{k,av}}$.

Resource Allocation in OFDM



- Available resources:
  - Subcarriers
  - Transmit power
- Channel is frequency-selective $\Rightarrow$ subcarriers not identical.

OFDM Resource Allocation Algorithms

- Channel Aware Only (CAO) Scheduling
  - Proportionally Fair (PF) subcarrier allocation [Rhee00]
  - PF subcarrier allocation + power optimization [Shen05]
  - Max utility subcarrier allocation + power optimization [Song05]
- Channel Aware Queue Aware (CAQA) Scheduling
  - MLWDF for OFDM-TDMA [Andrews00]
  - MLWDF at subcarrier level [Parag05]
- Our Work
  - Joint Subcarrier and Power Allocation (JSPA) approach
  - Optimize power allocation after each subcarrier is allocated

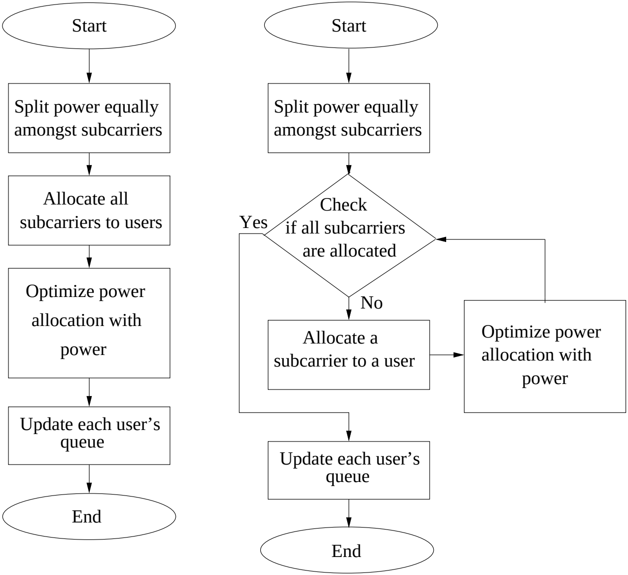
MLWDF for OFDM-TDMA

- All subcarriers allocated to a single user in each slot
- Select user i as:
  - $i = \arg\max_k \gamma_k W_k R_k$
  - W_k: Head-Of-Line (HOL) packet delay for user k
  - R_k: Rate achievable for user k (water-filling)
  - $\gamma_k = \frac{C_k}{R_{k,av}}$
  - $C_k = \frac{-\log \delta_k}{D_k}$ to achieve $P[\text{delay} > D_k] < \delta_k$
- Throughput optimal single-user scheduling rule
  - Maximum stability: achieves stable queues if any algorithm can achieve it
- Single-user scheduling in each time slot not optimal

Subcarrier-wise Allocation

- Approach 1: MLWDF at the subcarrier level [Parag05]
  - For each subcarrier n:
    - $i_n = \arg\max_k \gamma_k W_k R_{k,n}$
    - W_k: Head-Of-Line (HOL) packet delay for user k
    - $R_{k,n}$: Rate achievable for user k on subcarrier n
    - Power allocation needed to allocate subcarriers
    - Uniform/fixed power allocation assumption
- Approach 2: [Song04]
  - Mean packet waiting time instead of Head-Of-Line (HOL) packet delay
  - Other utility functions based on mean packet waiting time

Joint Subcarrier and Power Allocation



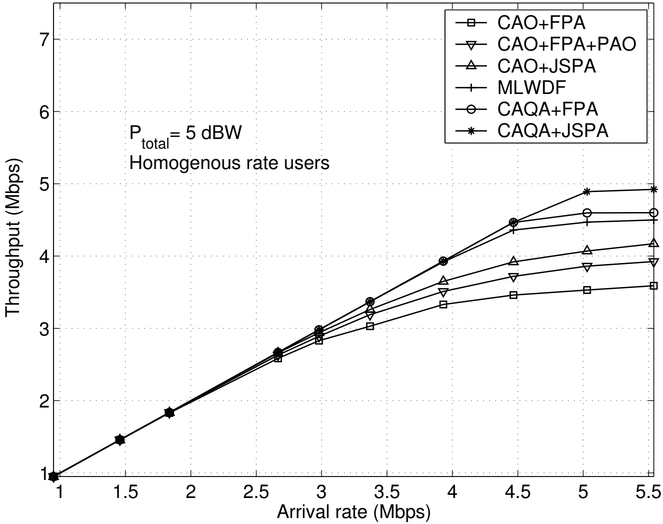
Joint Subcarrier and Power Allocation (JSPA)

- Optimal JSPA too complex
- Sub-optimal JSPA
  - Power optimization after each subcarrier is allocated leads to better allocation of the remaining suncarriers
  - Power allocation to each user proportional to the number of subcarriers allocated
  - HOL delay is estimated after each subcarrier is allocated
- Some practical constraints included
  - Discrete-rate constraint: Integer bit M-QAM constellations
  - Extension to band-wise allocation: reduced signaling/feedback

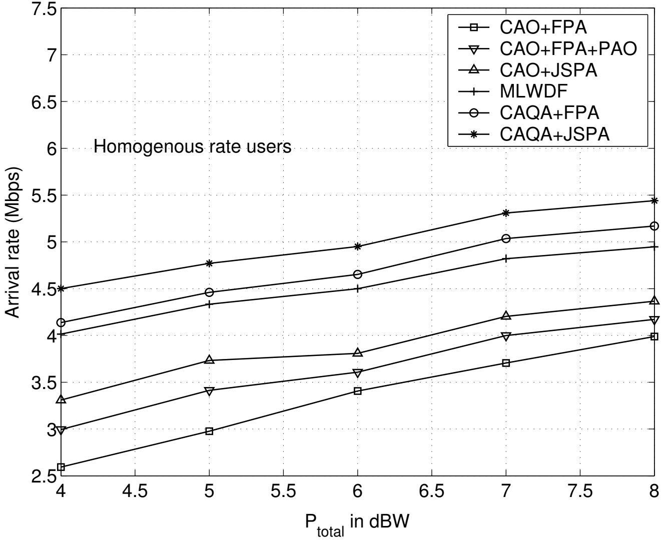
Simulation Setup

- 128 subcarrier OFDM system
- 12 users, Bernoulli packet arrival, 100 slot buffer
- 6-tap multipath channel, average channel conditions are different for each user
- QPSK to 64-QAM

Results: Throughput vs. Arrival Rate

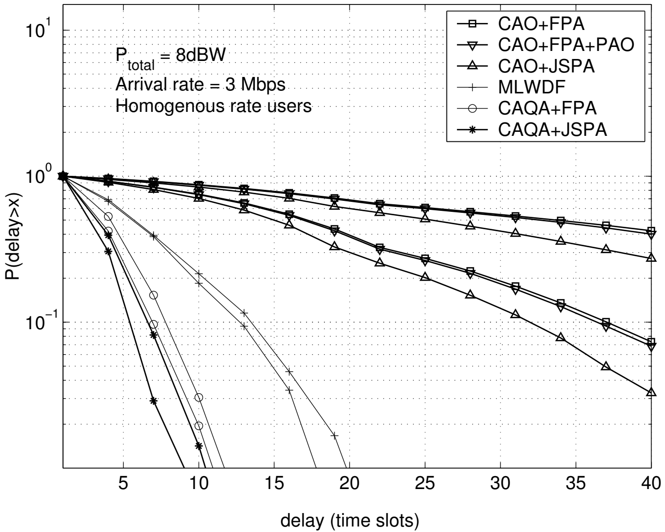


Results: Max. Arrival Rate vs. Transmit Power



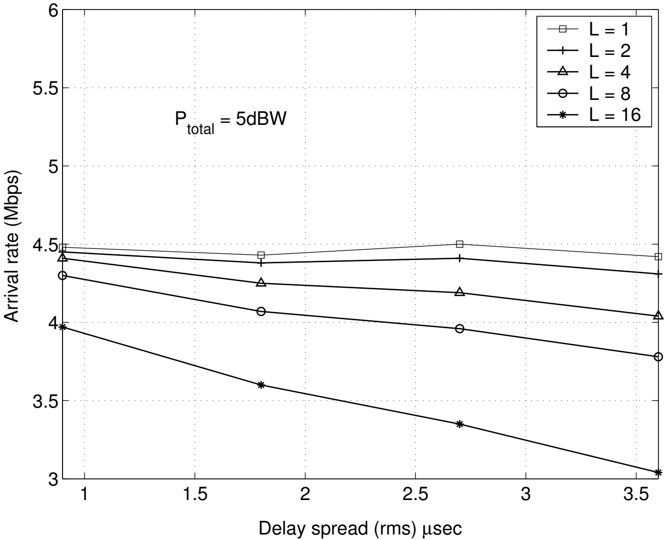
- Max. arrival rate for less than 0.5% packets dropped

Results: Delay Performance



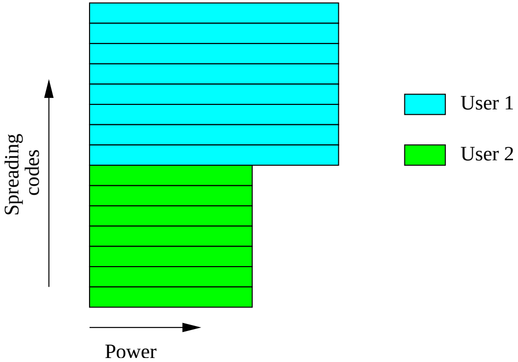
- Best and worst delay performance among users plotted

Results: Band-wise Allocation



- $L =$ Number of subcarriers in a sub-band

Resource Allocation in CDMA

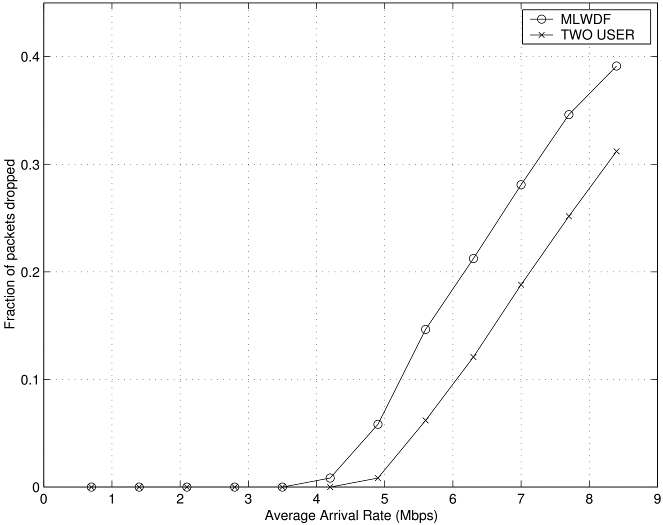


- Available resources:
  - Spreading codes
  - Transmit power
- For any given user, all spreading codes are similar (in terms of channel conditions).

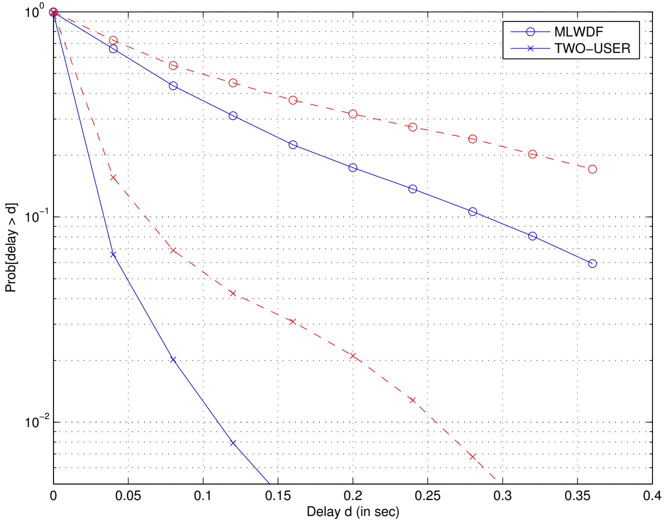
Multiuser Scheduling

- Most algorithms are single-user scheduling algorithms
  - Proportionally Fair [Tse02]
  - MLWDF [Andrews00]
- Recent results on multi-user scheduling algorithms
  - Greedy and pairwise greedy allocation [Kumaran05]
  - Gradient-based scheduling [Agrawal04]

Results: Maximum Supportable Traffic



Results: Delay Performance



Summary

- Dynamic resource allocation is essential to achieve high spectral efficiency
- Adaptation based on both channel and traffic information
- Some new results for OFDM and CDMA systems
  - Joint subcarrier and power allocation in OFDM
  - Multiuser scheduling in CDMA
- Several open problems:
  - Optimality
  - Quantifying the signaling/feedback overhead

References

- E. F. Chaponniere, P. Black, J. M. Holtzman, and D. Tse, "Transmitter directed multiple receiver system using path diversity to equitably maximize throughput," *U. S. Patent No. 6449490*, September 2002.
- M. Andrews, K. Kumaran, K. Ramanan, A. Stolyar, R. Vijayakumar, and P. Whiting, "CDMA data QoS scheduling on the forward link with variable channel conditions," *Bell Labs Technical Memorandum*, 2000.
- W. Rhee and J. M. Cioffi, "Increase in capacity of multiuser OFDM system using dynamic subchannel allocation," in *Proceedings of the 51st IEEE Vehicular Technology Conference*, vol. 2, Spring 2000, pp. 1085–1089.
- Z. Shen, J. G. Andrews, and B. L. Evans, "Adaptive resource allocation in multiuser OFDM systems with proportional rate constraints," *IEEE Transactions on Wireless Communications*, vol. 4, no. 6, pp. 2726–2737,

References

G. Song and Y. Li, "Cross-layer optimization for OFDM wireless networks-Part II: Algorithm development," *IEEE Transactions on Wireless Communications*, vol. 4, no. 2, pp. 625–634, March 2005.

P. Parag, S. Bhashyam, and R. Aravind, "A subcarrier allocation algorithm for OFDMA using buffer and channel state information," in *Proceedings of the 62nd IEEE Vehicular Technology Conference*, vol. 1, September 2005, pp. 622–625.

G. Song, Y. G. Li, J. L. J. Cimini, and H. Zheng, "Joint channel-aware and queue-aware data scheduling in multiple shared wireless channels," in *Proceedings of the IEEE Wireless Communications and Networking Conference*, vol. 3, March 2004, pp. 1939–1944.

References

R. Agrawal, V. Subramanian, and R. Berry, "Joint scheduling and resource allocation in CDMA systems," in *2nd Workshop on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt '04), Cambridge, UK*, March 2004.

K. Kumaran and H. Viswanathan, "Joint power and bandwidth allocation in downlink transmission," *IEEE Transactions on Wireless Communications*, vol. 4, no. 3, pp. 1008–1016, May 2005.