Dynamic Resource Allocation for Efficient Wireless Packet Data Communications

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Demand for mobile wireless internet access
Need support for multimedia data transfer
Broadband Wireless: Challenges

- High data rates and limited/expensive spectrum ⇒ 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:
  - $i = \text{arg max}_k \gamma_k W_k R_k$
  - $W_k$: 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
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Introduction

Problem

OFDM Resource Allocation

Our Algorithm

Results

CDMA Resource Allocation

Results

Summary

References

Joint Subcarrier and Power Allocation

Start

Split power equally amongst subcarriers

Allocate all subcarriers to users

Optimize power allocation with power

Update each user’s queue

End

Start

Split power equally amongst subcarriers

Check if all subcarriers are allocated

Yes

Optimize power allocation with power

Update each user’s queue

End

No

Allocate a subcarrier to a user

Optimize power allocation with power

Update each user’s queue
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 subcarriers
  - 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

Throughput (Mbps) vs. Arrival rate (Mbps)

- CAO+FPA
- CAO+FPA+PAO
- CAO+JSPA
- MLWDF
- CAQA+FPA
- CAQA+JSPA

$P_{total} = 5$ dBW
Homogenous rate users
Results: Max. Arrival Rate vs. Transmit Power

Max. arrival rate for less than 0.5% packets dropped
Results: Delay Performance

- $P_{\text{total}} = 8\text{dBW}$
- Arrival rate = 3 Mbps
- Homogenous rate users

Best and worst delay performance among users plotted
Results: Band-wise Allocation

$P_{\text{total}} = 5\text{dBW}$

$L = \text{Number of subcarriers in a sub-band}$
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

![Graph showing the fraction of packets dropped against average arrival rate (Mbps)].

- MLWDF
- TWO USER
Results: Delay Performance

![Graph showing delay performance comparison between MLWDF and TWO-USER algorithms.](image-url)
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


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