Helsinki University of Technology
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Flash-OFDM

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S-72.4210 PG Course in Radio Communications
21.3.2006

Outline

1. Background

- Two solutions to the problem of wireless mobility:
- A packet switching based system
  - an extension of local area networks and the Internet.
- A circuit switching based system
  - an extension of the digital phone network.
- In the wired world, much activity has been focused on the integration of the packet- and circuit-based approaches, such as asynchronous transfer mode (ATM) and voice over IP.
- Flash-OFDM is a packet switched system that includes also voice.

A discussion of the state in wireless world can be found in [2].

1.1 Circuit switched vs. packet switched

- Circuit switched systems exist only at the physical layer which uses the channel resource to create a bit pipe.
- No control of the pipe required once it is created.
- Packet switched systems are very efficient for data traffic but they require control layers in addition to the physical layer that creates the bit pipe.
- The MAC layer is required for the many data users to share the bit pipe.

1.2 Data traffic vs. voice traffic

- Data traffic is much more unpredictable
  - The data rate varies, when it arrives varies and the message size varies
  - There are many users simultaneously sharing network recourses in a sporadic manner
- Admission control problems.
- Very different requirements in terms of reliability.
- Data traffic has different and wider range of services which have different requirements.
- Data service can be characterized by its priority => a user may have a service level agreement (SLA) (rate, latency).

1.3 Mobile, wireless data

- Conventional wireless systems, including 3G, were fundamentally designed for circuit switched voice.
- And therefore designed primarily at the physical layer.
- The choice of CDMA was also dictated by voice requirements.
- The goal is to have data and voice traffic in the same network.
- New air interfaces must be designed and optimized across all the layers of the protocol stack, including MAC and networking layers.

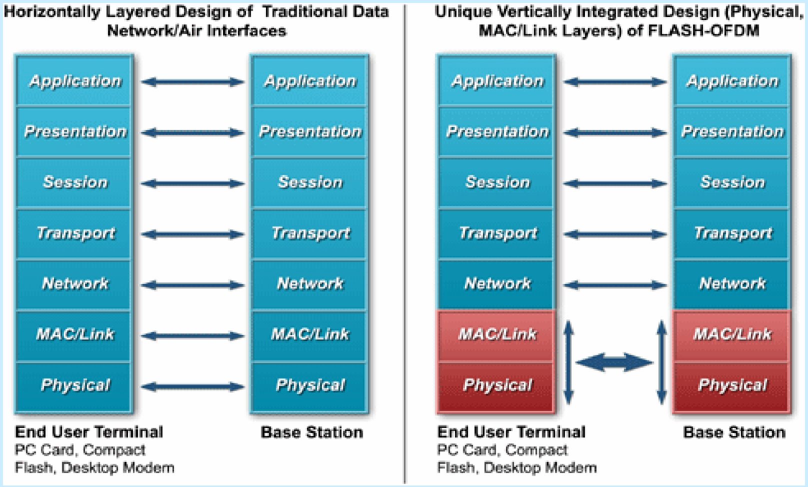
1.3 Mobile, wireless data

- A difficult performance challenge for TCP/IP protocols
- TCP was desinged and optimized around reliable wireline links where BER and FER are lower than that typically achievable wirelessly.
- When TCP encounters dropped packet, it assumes that there is a congestion, rather than the link itself being unreliable.
- Also the slow start of TCP can dramatically add to latencies.
- The RTT latency and latency jitter directly impact the obtainable throughput.

2. FLASH-OFDM

- An example of a cross layer optimization is the FLASH-OFDM technology.
- The choice of OFDM as the multiple access technology is based not just on physical layer considerations but also on MAC, link and network layer requirements.
- There is plenty of room to exploit the high degree of flexibility of radio recource management in the context of OFDM.
- FLASH-OFDM is an all IP-technology.

2. FLASH-OFDM



2.1 Design objectives

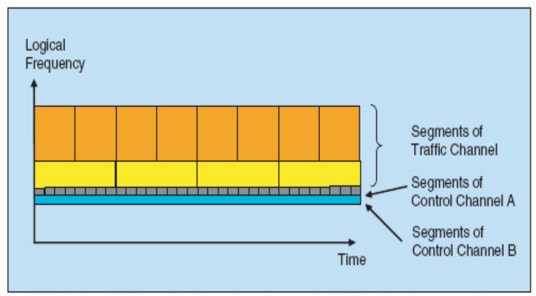
- Spectrally efficient, high capacity physical layer
- Packet-switched air interface
- Contention-free, QoS-aware MAC layer
- Support for interactive data application including voice
- Efficient operation using all existing Internet protocols (TCP/IP…)
- Full vehicular mobility
- Low cost

2.2 Physical layer

- FLASH-OFDM uses fast hopping across all tones in a pseudorandom predetermined pattern, making it a spread spectrum technology.
- The frequency reuse is 1.
  - Different base stations use different hopping patterns and each uses the entire available spectrum
- In a cellular deployment this leads to all the advantages of CDMA systems:
  - including frequency diversity
  - intercell interference averaging -- a spectral efficiency benefit that narrow band systems like conventional TDMA do not have.

2.2 Physical layer

- A transmission unit is called a segment, which consists of one or a few tone-hopping sequences over one or a few OFDM-symbols.
- In fact, even a single information bit can be transported with little overhead.



▲ 6. Illustration of traffic and control channel segments. Each rectangle represents a segment.

2.2 Physical layer

- The channel coding and modulation are carried out on a per-segment basis and can be individually optimized for each of the channels.
- For example low density parity check (LDPC) codes can be used in a traffic-channel segment, which is relatively large, but cannot be used in a small control-channel segment.
- To maintain the orthogonality in the uplink, the OFDM symbol boundaries of the signals from all wireless stations have to be aligned with the radio access router receiver window. => Need for timing synchronization.

2.2 Physical layer

- Closed-loop timing control is used for timing synchronization.
- As closed-loop timing control is intended to compensate for the variation of the propagation delay due to human mobility, which is at much slower rate than the speed of the signal propagation, the required rate of closed-loop timing control is very slow.
- For example, a rate of once every few seconds is sufficient for the mobile velocity of 60 miles per hour.
- Therefore, the overhead is very little.

2.3 Mac and link layers

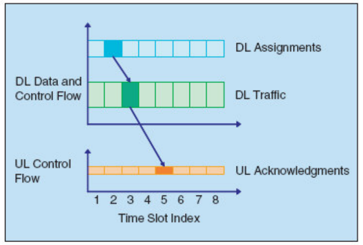
- The most significant advantage of FLASH-OFDM for data is at the MAC and link layers.
- FLASH-OFDM takes advantage of the granularity of OFDM in its control layer design.
- The ability to send segments of arbitrary size enables the MAC layer to perform efficient packet switching over the air
  - an acknowledgement is essentially a single bit so a very small acknowledgment segment can be dedicated, thereby providing a quick feedback.

2.3 Mac and link layers

- Link layer uses local (as opposed to end-to-end) feedback to create a very reliable link from an unreliable wireless channel, with very low delays.
- A given segment can be dedicated for use by a specific wireless transmitter to allow contention free control information to radio access router.
- A given segment can be dedicated for use with predefined functionality so that there is no need of sending overheads, such as message headers.
- The network layer’s traffic therefore experiences small delays and no significant delay jitter.

2.3 Mac and link layers

- The traffic channel is a series of traffic segments and the BS controls their usage through the assignment channel.
- There is a slaving between an assignment segment and a traffic segment.
- The WT decodes the assignment segment and on seeing an identifier that matches the one allocated to it, proceeds to decode the corresponding traffic segment.



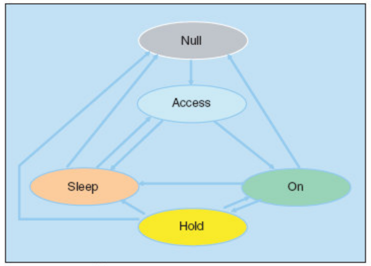
▲ 7. Traffic control slave structure.

2.3 Mac and link layers

- A similar slave structure exists between the assignments on the downlink, the traffic segments on the uplink, and the acknowledgements on the downlink to control the uplink traffic flow.
- The slave structure as described above also facilitates multicast of traffic.
- The assignment indicates then a multicast group identifier.
- This allows for a native support of multicast and an efficient usage of the air link bandwidth.

2.3 Mac and link layers

- The on state is the main data transaction state and the WT is power and timing controlled.
- The WT in the hold state is timing controlled.
  - WT transmits a low periodicity signal on the uplink
- The sleep state is the main power-saving mode.
  - The WT periodically wakes up and listens to pages.



▲ 9. State transitions.

2.3 Mac and link layers

- Objectives for having these states:
  - To facilitate various power-save modes for the WT and thus extend battery life.
  - Another is to support a large population of WTs.
- On power up, a WT goes through the access state.
- The hold state augments the on state and provides some power saving.
- The sleep state provides the most power savings.
- The system can accommodate more WTs in the hold state than in the on state and in the sleep state than in the hold state.

3. Fairness vs. efficiency

- Spectral efficiency is traditionally measured by aggregate throughput.
- That may lead to an unfair situation to those user far from a base-station.
- On the other hand absolute faineess may lead to low spectral efficiency.
- Cross layer design is thus profitable.
- Fairness vs. efficiency problem has been well studied in economics

3.1 Utility theory

- Utility function maps a network resources a user utilizes into a real number.
- The utility function should be a nondecreasing function of the network recource in question.
- Reliable data transmission rate is often the most important factor to determine the user satisfaction, thus U(r), where r is the data rate.
- U(r) = r if utility is just a throughput.
- When utility function is used to capture the user's feeling such as the level of satisfaction it can not be obtained only through theorethical derivations but objective surveys.

3.1 Utility theory

- In economics, utility functions are used to quantify the *benefit* of usage of certain recources.
- In communication networks, utility functions can be used to evaluate the degree to which a network satisfies *service requirements* of user's applications rather than in terms of system-centric quatities like throughput, outage probability, packet drop rate etc.
- Also for cross layer optimization between the physical and media access control (MAC) layers.

3.1 Utility theory

- In [4] the authors formulate the cross-layer optimization problem as one that maximizes the average utility of all active users subject to certain conditions.
- The conditions are determined by adaptive resource allocations schemes.
- Utility function has been used in wireline networks for flow control, congestion control and routing.
- In wireless for CDMA power allocation, pricing of uplink power control.

4. Conclusions

- OFDM is well positioned to meet the unique demands of mobile packet data traffic.
- In order to seamlessly unwire all the IP applications all layers of the OFDM air interface need to be jointly designed and optimized from the ground up for the IP data world.
- Flash-OFDM is one example of this kind of cross-layer optimization.
- Utility theory can be used for cross layer optimization between the physical and media access control (MAC) layers.

Homework

In [4] the utility theory is used for cross-layer optimization. Explain in your own words what proportional and min-max fairness means. Give also a short comparison on those schemes.

References

[1] Flarion Technologies, "OFDM for Mobile Data Communications" White paper, March 2003.

[2] P. Newman, Netillion Inc. "In search of the All-IP Mobile Network", *IEEE Radio Communications*, Dec 2004

[3] R. Laroia, S. Uppala, and J. Li, "Designing a broadband mobile wireless network," *IEEE Signal Processing Mag.*, vol. 21, no. 5, pp. 20-28, 2004.

[4] G. Song, Y. Li,"Cross-layer optimization for OFDM wireless networks-part I: theoretical framework," *IEEE Transactions on Wireless Communications,* vol. 4, no. 2, pp.614- 624, March 2005