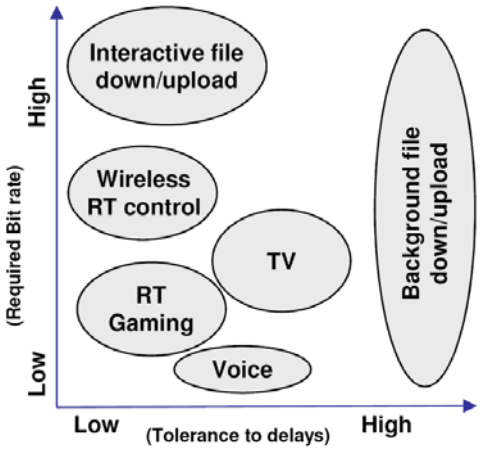
Control Challenges in Mobile Telecommunications

Mobile telecommunications technology is having an unprecedented impact on human society. Currently, there are more than 6.8 billion cellular subscribers worldwide, and more than 4 million new phones are sold per day! Global revenue from subscriptions exceeds $6.5 trillion annually. New services are also appearing, including TV, web browsing, tethering, and real-time gaming. As in all areas of technology, the successful operation of modern telecommunication systems depends in part on highly sophisticated real-time control. The opportunities for advanced control are enormous, but the area poses new and interesting challenges. For example, the control problems in telecommunications have their own distinctive characteristics, including varying demands on data rate and delay latency (see figure below). Also, the control is necessarily carried out over the telecommunication channel itself, giving rise to networked control issues.



Bit rate/delay issues for mobile services (RT: real time)

Control in Telecommunications

Control appears at various levels in mobile telecommunications:

Power control: Used to adjust the signal-to-interference ratios (SIRs) of users so they are maintained at an appropriate level at the base station. These loops operate with significant delay, use coarsely quantized control signals, which limits the slew rate, and are subject to fast and large channel gain variations.

Link adaptation: Used to optimize performance by controlling the transmission rate jointly with the transmit power. Link adaptation uses quantized measurements related to signal quality to select transmission rates and modulation.

Scheduling: To maximize certain performance measures, 3G, 4G, and 5G cellular systems schedule users in the downlink and the uplink in real time; 4G and 5G systems schedule users in both frequency and time to capitalize on favorable instantaneous channel conditions.

Backhaul control: When bit rates over the air-interface increase, so does the need to control the data flow upstream of the radio link to minimize round-trip delays and ensure that data is always available for transmission to scheduled users.

Multipoint transmission and reception: Techniques such as coordinated multipoint transmission utilize noncollocated antennas. Data synchronization and inter-transmit-point control loops are then needed to align the powers and the delays for the various antennas.

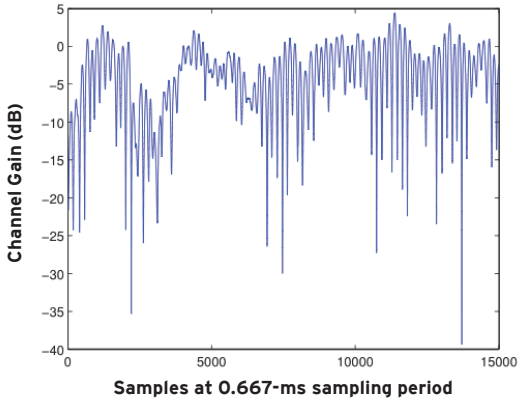
Telecommunications in Control

Not only is control central to modern mobile telecommunication systems, the reverse is also true; that is, the next-generation control systems are likely to be wireless-based due to flexible connectivity and reduced costs.

In the ongoing definition of 5G, not only bit rate but also delay is at the focal point. Examples of applications under consideration include:

- Vehicular control, e.g., collision avoidance and platoon driving
- Haptic control, e.g., advanced gaming and remote surgery

Wireless round-trip delays of the order of 1 ms are needed to enable these emerging applications.



Channel gain variation at 3 km/h

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Challenges

Challenges associated with telecommunication control problems include:

Power control

- Heavily quantized signals (1 or 2 bits)
- Delays
- Lost control signals
- Highly variable channel fading
- Significant nonlinearities
- Multivariable interactions

Scheduling

- Large and variable delays
- High uncertainty in channel gains

Link adaptation

- Coarsely quantized feedback
- Delays
- Discrete control action

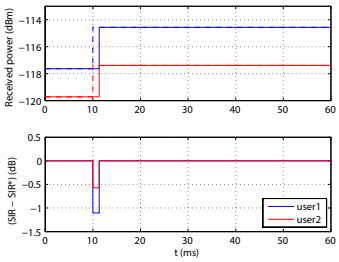
Opportunities for Advanced Control

The nature of the control challenges in telecommunications provides exciting opportunities for sophisticated control tools; however, the application of these tools in the telecommunications context raises new, and as yet not fully solved, challenges.

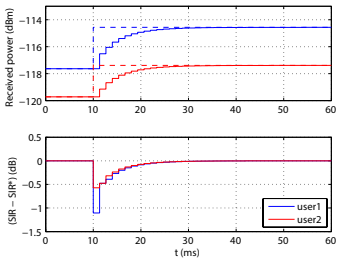
- New ideas in networked control are needed for the power control loops. This is difficult because only 1 bit (3G) or 2 bits (4G) can be sent per sample and bits may be lost.
- New scheduling algorithms are needed that exploit the dynamics and inherent constraints of the scheduling loop. High (stochastic) uncertainty, variable delays, high complexity, short sampling periods, and the need for low latency make this extremely challenging.
- Novel implementations of nonlinear filtering could be applied to load estimation and for prediction of channel fading, grant utilization, and intercell interference. However, high state dimension, severe nonlinearities, and fast sampling rates all pose challenges.
- New insights into decentralized control are needed to implement solutions. The stochastic nature of the problem and high demands on quality of service for users make this challenging.

An Example of the Use of Advanced Control in Mobile Telecommunications

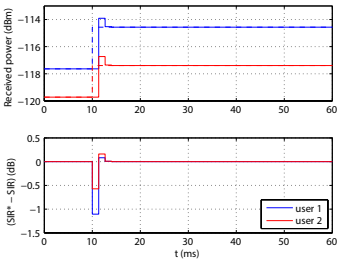
The following figures relate to inner-loop power control for 3G systems.



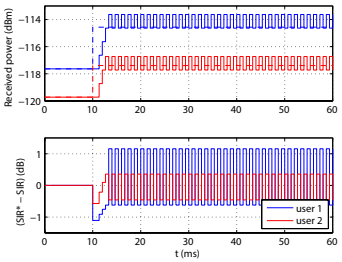
(a) One user at a time



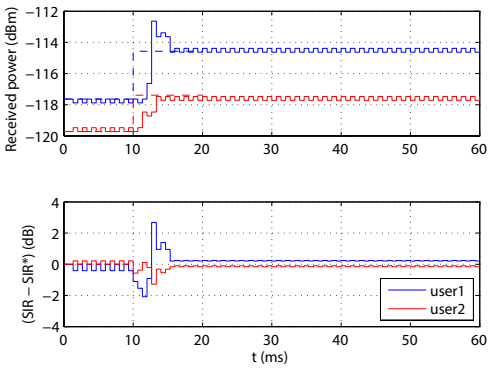
(b) Impact of multivariable interaction



(c) Impact of decoupling



(d) Impact of quantization



(e) Impact of nonlinear adaptive control with 1-bit quantizer

Figure (a) shows a minimum-variance inner-loop power controller for one user at a time with no control quantization.

Figure (b) shows that multivariable interactions significantly degrade the regulation performance when multiple (in this case, two) users are considered.

Figure (c) shows the impact of using a nonlinear decoupling algorithm. Note that the performance is now very similar to that achieved for a single user.

Figure (d) shows the impact of control signal quantization (to 1 bit), which undermines the gains achieved by decoupling.

Figure (e) shows that the decoupling performance is largely recovered by using a sophisticated nonlinear adaptive controller that optimally compensates for the 1-bit constraint.