CHAPTER 3

WIRELESS COMMUNICATIONS RESEARCH IN CHINA

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INTRODUCTION

Wireless communications is expected to grow dramatically in Asia, mainly in China. In order to address this growth advanced wireless communication systems need to be implemented. The focus of this chapter is on research activities related to wireless communications in Hong Kong, Taiwan, and mainland China. First the goals of wireless communication systems and the challenges of wireless communications are discussed along with some of the research activities in China. The conclusion is that Hong Kong and Taiwan have good universities (equivalent to a top 25 US university) but there is only a handful of them which can produce only a small number of engineers. On the other hand, mainland China can produce many more engineers but not currently with the same quality. In the remainder of this chapter the goals and challenges of a mobile communication system are examined. Several approaches for overcoming these obstacles are identified, followed by a discussion of the relevant activities in Taiwan, Hong Kong and mainland China. The activities in mainland China do not represent a comprehensive evaluation because of the lack of data.

WIRELESS COMMUNICATIONS GOALS AND CHALLENGES

The goals of wireless communication systems includes high data rate (high bandwidth efficiency), low power (high energy efficiency), large capacity (number of users), interoperability, low complexity/cost, low delay for voice, and high reliability for data. These goals are difficult to achieve in light of the challenges of a mobile communication channel for which the signal amplitude and phase is constantly changing due to the constructive and destructive cancellation of signals in a multipath fading environment. The channel characteristics can be characterized as propagation loss, shadowing and fast (multipath) fading. The propagation loss depends on the distance from the base to the mobile. This is typically modeled as a loss in power proportional to some power of the distance. The exponent is typically between 2 and 4. Fast fading is due to the fact that there are multiple paths between the transmitter and receiver. If the carrier phases of different paths from the transmitter to the receiver (at a particular frequency) add destructively then the envelope of the signal can be greatly attenuated. On the other hand if the amplitudes add constructively the amplitude becomes larger than the amplitude on a single path. Since the phase depends on frequency, the fading amplitude is frequency dependent. If the bandwidth of the transmitted signal is wide enough so that the amplitude changes over the bandwidth of the signal then it is said that the channel is frequency selective. If the bandwidth is narrow enough so that there is very little change in the fading amplitude, then the channel

is said to be frequency nonselective. For some modulations (high data symbol rates) techniques, frequency selective fading cause severe intersymbol interference.

In addition to the challenge of dealing with the fading amplitude, the goals of energy and bandwidth efficiency are difficult to achieve. Shannon derived fundamental limits on the bandwidth efficiency and power efficiency for communication systems assuming ideal devices. However, typical power amplifiers are power efficient only when operating in saturation (close to or in the nonlinear region of the amplifier). In saturation amplifiers are typically nonlinear. The nonlinearity, when operating on a bandwidth constrained signal generate intermodulation products which has the effect of widening the spectrum of the signal. To avoid saturation the input amplitude of the signal driving the amplifier can be reduced or backed-off. The larger the back-off the more linear the amplifier operates. However the larger the back-off the more power that is wasted in the amplifier. In cellular systems the goal is low power consumption for the mobile. However, the power consumption is not as big of a concern at the base station. This can provide an opportunity for clever system design. On the other hand, wireless networks without base stations have a different type of asymmetry whereby nodes in the center of the network are called on to forward more traffic to neighboring nodes compared to nodes at the edge of the network. These nodes will likely consume more power.

A final challenge in designing wireless communication systems (especially cellular systems) is the issue of intellectual property. While first generation systems all used well developed technology (analog frequency modulation), second generation systems used technology that contained significant intellectual property. This has been one of the leading factors driving 3G standards. Thus, while the technical issues are discussed below for these systems, the overall conclusions should be considered in light of the ownership of intellectual property.

APPROACHES AND TECHNICAL ISSUES

There are a number of approaches to overcoming the challenges of wireless communication channels. These include the network architecture, multiple-access techniques, coding techniques and modulation. It should be emphasized that these can not be considered separately as they are intimately coupled. Nevertheless these topics are discussed individually.

Network Architectures

The dominant architecture for mobile communications is cellular systems in which mobile users communicate through a fixed base station. In a cellular system frequencies are reused by users sufficiently separated geographically (e.g. not in neighboring cells). Users moving from one cell to another cell, while in the process of a call, must handoff from one base station to another base station. The other architecture is call ad-hoc networks in which there are no fixed base-stations and packets must be routed through intermediate nodes in order to reach the final destination. Ad-hoc networks have been more applicable to military communications systems than commercial systems. In ad-hoc networks with mobile nodes each user must keep track of paths to each destination. This can cause significant overhead in transmissions and reduce the capacity of the system. However the lack of base stations potentially make the network more robust to failures.

Multiple-Access/Multiplexing

There are a number of different techniques for users to access wireless channel. These include frequency division multiple-access (FDMA), time-division multiple-access, code division multiple-access. Original cellular systems all used FDMA whereby users in the same cell were assigned different frequencies and frequencies were used in cells sufficiently separated geographically. These systems used analog frequency modulation (FM). Many countries in these first generation cellular systems used different frequencies (e.g. European countries). Second generation systems were developed to provide increased capacity, better bandwidth efficiency and well as low rate data services and in Europe a single standard across countries. The multiple-access techniques used include TDMA, TDMA/FDMA and CDMA. Most cellular standards use

one set of frequencies for the uplink (mobile-to-the base station) and a different set of frequencies for the forward link (base station-to-mobile). This allows full duplex transmission. However, the fast fading amplitude on the reverse link is different than on the forward link. An alternative is time duplexing (TD) whereby the base station and the mobile station use the same frequency but do not transmit at the same time. The advantage of this is the reciprocal nature of the channel allows the transmitter to use knowledge of the channel in determining the coding and modulation that will be used. The reciprocal nature of the channel implies that the fading amplitude of the transmission from the base to the mobile and the fading amplitude from the mobile to the base are identical.

Coding

Error control coding is an essential element of a well-designed communication system. In a typical system information is used as the input to an encoder which adds redundant data (data dependent on the information). The transmitter then sends the information along with the redundant data over the channel. At the receiver the decoder attempts to determine the information based on the total received (but unreliable) data symbols. The use of coding typically increase the bandwidth of the modulated signal since the redundant data, as well as the information, needs to be transmitted in the same time as the information is produced (e.g. a voice packet). The advantage is that the amount of energy needed for each bit, for a given reliability, can be reduced by a significant amount (e.g. from 9dB for benign channels to 40dB for faded channels). This tradeoff of power efficiency for bandwidth efficiency is typically worth it in cellular systems and very important in satellite systems. Typical second generation cellular systems use convolutional codes. In the 90's a new class of codes (turbo codes) was invented and low density parity check (LDPC) codes were rediscovered. Both turbo codes and LDPC need channel information (e.g. fading amplitude) to achieve the maximum gain in power efficiency.

Modulation

After data is encoded a modulator maps the discrete data into waveforms suitable for propagating and such that the data can be determined. One classification of signals is as constant envelope modulation schemes and nonconstant envelope schemes. Constant envelope schemes, as the name implies, have envelopes which do not vary with time. The advantage of these schemes is that no distortion occurs when these types of signals are passed through a nonlinear amplifier. However the constant envelope nature of the signal forces the signal to have a fairly large bandwidth. On the other hand nonconstant envelope signals can have a very narrow bandwidth. However when these signals are amplified by a power amplifier operating in a power efficient region, intermodulation products cause the signal spectrum to expand and even causes some self interference (intermodulation products that fall within the original signal bandwidth). The second generation European standard (GSM) used constant envelope modulation while the second generation North American standards (IS-54 and IS-95) used nonconstant envelope modulation. This implies that there is not a convincing argument one way or another as to which technique is better.

RESEARCH ACTIVITIES IN TAIWAN, HONG KONG AND CHINA

In this section we discuss research being conducted at several universities in the area of wireless communication systems. In particular we focus on coding, modulation and multiple-access techniques for wireless communication systems.

National Taiwan University

At the National Taiwan University there is research being conducted on various aspects of wireless communications. Special emphasis is given to the areas of timing and phase estimation in the presence of multiuser signals as well as low complexity (non iterative) decoder design.

National Chiao Tung University

At National Chiao Tung University in Taiwan Dr. Sun is conducting research in the area of coding and modulation for wireless communication systems. One aspect of his research involves type-II hybrid ARQ protocols using turbo like codes constructed from product codes. These are codes that can yield high rates without the necessity of puncturing. Combined with a type-II hybrid ARQ protocol Dr. Sun has demonstrated significant improvements in throughput and delay compared to type-I ARQ and pure ARQ. Other advantages of these techniques are that the error floors present with regular turbo codes are eliminated and they have a more graceful degradation when the block length is reduced. In addition to ARQ protocols, research is being conducted on joint decoding and channel estimation algorithms, noncoherent receivers for direct-sequence spread-spectrum (CDMA) systems. power control algorithms for cellular systems. This University has superb facilities for semiconductor research as well as channel propagation measurements.

Hong Kong University of Science and Technology

The Hong Kong University of Science and Technology is a relatively new university. The faculty there has created a center for wireless information technology (CenWit).

The goal of CenWit is to be an umbrella organization for the research in wireless communications including circuits, signal processing algorithms, protocols, devices and antennas. The research directions of CenWit include wireless multimedia communications, broadband wireless access, RF and low power VLSI and wireless networking. In their wireless multimedia project they developed a scalable 1Mbps system carrying MPEG-1 quality movie along with high fidelity audio. Other work includes multiuser detection algorithms and concatenated coding for CDMA, channel estimation, timing recover, power allocation and interference cancellation for OFDM.

Overall, Hong Kong University of Science and Technology has a group of young energetic faculty who are working together in multidisciplinary projects.

University of Hong Kong

The University of Hong Kong is conducting research on a variety of topics related to wireless communication systems. This includes multicode wideband CDMA whereby users are assigned multiple spreading codes for transmission. Multicode transmission techniques are one technique for increasing the data rate for a user without changing the bandwidth of the channel. However, multicode CDMA causes high envelope variations and multicode interference. At the University of Hong Kong they have investigated a multistage interference cancellation approach for multicode transmission with coherent processing at the receiver, multistage cancellation, and reduced complexity. In addition they have investigated coding techniques that reduce the envelope fluctuations by as much as 6.5dB. This reduction allows for the use of an amplifier operating closer to saturation and thus allows for significant power savings. Other relevant research topics at the University of Hong Kong include adaptive modulation, hybrid ARQ using turbo codes, sequence design for spread-spectrum systems using filter bank theory, automatic frequency control (AFC) algorithms based on maximum likelihood methodology, digital timing recovery, bandpass AD converters and channelization for software radios.

Beijing University of Posts and Telecommunications

The Beijing University of Post and Telecommunications is conducting research relevant to cellular systems. One of the research projects involves quasi synchronous CDMA in which the relative arrival time of signals from different users at the base-station are controlled to be within a couple chips of each other. In this project faculty at BUPT investigate sequences that have low cross correlation properties when the time offset between different users is restricted to a small number of chips. Compared to conventional sequences (e.g. Gold sequences or Kassami sequences) the error performance is shown to be as much as an order of magnitude smaller for small time offsets but for large offsets approaches the same performance of conventional sequences. This type of research is probably useful for the 3G standard based on time division

duplexing whereby users need to be fairly tightly synchronized. While other research topics were discussed the panel members were unable to find explicit results being obtained at BUPT.

Tsinghua University

Several relevant research projects are being conducted here. One of these is the 3GPP (third generation partnership project) WCDMA development. Another is wireless multimedia communications. In this project they are investigating source controlled spreading along with channel coding.

CONCLUSIONS

In conclusion, the limited number of universities in Taiwan and Hong Kong are conducting quality (but limited quantity) research. In addition the focus of the research is less oriented towards fundamental basic research and more oriented towards applied research than universities in the U.S. In addition the number of engineers they produce is not able to support the demand. In mainland China the quality of engineering education appears to be lower than in Hong Kong and Taiwan but the number of engineers produced per year can meet the demand of industry. China is clearly playing catch up in regard to cellular systems. In conjunction with Siemens they have proposed a standard based on time division duplexing and CDMA. As mentioned earlier, this has several advantages compared to frequency division duplexing, which is used by most of the other standards. However, given the time it took for Qualcomm to deploy CDMA in the early-mid nineties it is not clear if Siemens/Datang will be able to work out the bugs before the demand for cellular increases. Currently one of the operators is deploying CDMA 2000 as opposed to the system developed jointly by Siemens and Datang. It is not clear what role the government will have in determining the standard that is used by operators.