Project Description

Cognitive Radio	Wireless spectrum is among the most heavily regulated merchandise all over the world. The resource is finite and the cost for spectrum is skyrocketing with the increasing demand of wireless services. For instance, thirty-five billion dollars were yielded in Britain and over forty-six billion in Germany during the auctions for 3G (third-generation) wireless communication licenses. Thus, efficient utilization of spectrum is critical to the success in the wireless communication era.

Spectrum usage is highly variable based on time, frequency, and geometric locations. Cognitive radio technologies have been proposed to improve spectrum efficiency by using radio frequencies that is temporally unused or under-utilized. In particular, radio transmitter/receiver have been designed to intelligently detect whether a particular segment of the radio spectrum is being used currently, and to jump into (and out of if necessary) the temporarily under-utilized frequency (crowded frequency) rapidly, without interfering with the transmissions of the authorized users.

Because cognitive radio is a relatively new technology, there are questions to be answered all over, including device, physical layer, MAC (medium access control), networking, and application layer. In this project, we focus on the MAC and networking layer.

Medium Access Control	Medium access control plays an important role to explore under-utilized spectrum that mitigates the scarcity of spectrum resource. We focus on a decentralized scheme, where there exists no central controllers, e.g., in an ad hoc network. An ad-hoc network is a network without existing infrastructure support. Its applications include military actions, emergency rescue, meeting, festivals, etc. Another decentralized scenario is that different users belong to different authorities, e.g., users of different wireless LANs (local access network). We plan to study the following problems.

In a wireless system, the transmitter and the receiver have to use the same frequency for communications. They have different locations and thus may observe different frequency usage. How can they coordinate with each other to communicate at a desired frequency without interfering with the authorized users? In particular, when one detects an authorized user, how can they switch to a different frequency rapidly enough to avoid interference to the authorized users? One possible solution is to use their authorized frequency for control signals and as default communication channels. The difficulty is that the condition in the default channel is unpredictable, e.g., there may be users nearby using the same channel. Jumping back to the default frequency suddenly may interrupt other communications. Another possible solution is to continuously searching for other under-utilized frequencies as backups. In general, such access problems deserve studies in depth.

In the context of cognitive radio, multiple users may want to share an unused frequency band. For example, in a WLAN, the designated spectrum is often crowded, and thus multiple cognitive radio users may switch to another frequency during a same time period. An interesting question is how to distinguish between the authorized users and other cognitive radio users. Radio signals are indistinguishable and the communications can be encrypted. Thus, eavesdropping on the communication content is not a feasible solution. Instead, one possible approach is to design different communication patterns. A naive idea is that the authorized user always increases its transmission power when detecting other transmissions while a cognitive user decreases transmission power and listens. When multiple cognitive users sharing the same frequency band,
efficient utilization/resource allocation is important; i.e., how can different cognitive users coordinate with each other and fully utilized the spectrum, spacial, and temporal diversities. This is a decentralized dynamic resource allocation problem, which is not well-studied.

**Spectrum Leasing** Wireless spectrum is regulated by FCC (Federal Communication Commission) in USA. FCC approved short-term and long-term spectrum leasing among different wireless service providers in 2003 and has been promoting the research of cognitive radios in the context. The new spectrum leasing rules can result in improved service for the nation’s millions of users of cell-phones and other wireless devices. The sharing of the spectrum can provide better coverage and access capability for mobile users, and boost the development of innovative wireless services that requires high bandwidth and good qualities at affordable prices. However, there exists little research on appropriate models and analysis for spectrum leasing. This lies the playground of the proposed research.

**Metrics** An analogy of real-time spectrum trading/leasing is in the hotel industry where overbooked hotels refer their guests to an alliance with vacancies. Similarly, in a certain geographic location, an overly crowded wireless service provider can lease spectrum from an alliance with under-utilized resource. However, these two industries are very different. First, wireless networks have soft capacities and thus to quantify a service and its value is a first step toward understanding the spectrum sharing among multiple service providers.

We consider the case where the lessor and lessee share the spectrum. In a wide-band system, the signal of a user is modulated to occupy a spectrum that is much wider than the spectrum needed for its own communication, and the signals of multiple users share the same spectrum. An example of a wide-band system is a system using CDMA, the most popular technology for the third and future generation wireless networks. Such a wireless system is an interference limited system where we can trade quality for capacity and vice versa. For example, a base station may accommodate 100 voice users with good qualities or 120 phone calls where each user’s phone call is more noisy. In such a system, customers of lessors and lessees share the same spectrum. Thus, to define the performance metrics is important to quantify a lease and its associated value. We propose to consider the following metrics:

- In the downlink of a CDMA system, the transmission power at the base station is considered as resource since the system is interference limited. Thus, the transmission power at the base station to a particular user can be considered as the cost for its communication.

- In the uplink of a CDMA system, the transmission power of the mobile user or the received power level at the base station can be used as cost metrics.

- In a time-slotted system, time is the resource, and thus a natural metric.

- The data rate received by the user can be used as a metric.

In a wireless system, it may consume the system different amount of resources to achieve the same data rate for users with different channel conditions. For instance, a user far away from the base station or in deep fading environment may consume much more power than a user close to the base station with good channel conditions. Using different metrics may result in different behaviors of service providers. For example, if the data-rate metric is used, a lessee may tend to assign a user in a bad channel condition to the lessor’s resource. Thus, a thorough understanding
of the implication of such performance metrics is important to the design of leasing schemes and resource allocation among wireless service providers.

**Service Modeling and Analysis**  As discussed earlier, wireless networks have soft capacity and to quantify the service is important. In addition, compared to a hotel industry, a wireless system is far more dynamic. It is possible that after leasing resource to other service providers, a service provider does not have sufficient resource to satisfy its own committed customers in the near future, which results in revenue losses rather than gains. Thus, the decision making is non-trivial.

There is no existing models for the leasing of wireless spectrum. We focus on short-term leases where service providers lease resource in real-time when congested. Our conjecture is that different wireless service providers will have an overall agreement to share the spectrum upon request. When congested, a service provider will query its allied service providers in the same geographic location whether they have additional capacity. An allied service provider replies with the information of its available capacity and the associated price. The price may depend on the current channel usage of the ally. Because there may exists multiple queries and multiple replies, real-times auctions and/or negotiations may occur. If a real-time agreement is reached, the customer can use cognitive radio to switch to a different frequency.

It is our interest to develop good leasing models that are tailored to the characteristics of wireless networks. I would like to further develop and compare the following possible service models.

- The two parties agree on a certain amount of period and frequency band for lease. The advantage is both lessor and lessee have a clear expectation of the agreement. The disadvantage is that the mobile customer may terminate (or leave the location) much earlier or later than the agreement.

- The lessee can terminate the lease at the termination of the customer. The lessee enjoys the flexibility at the cost of the lessor, and thus may pay a higher unit fee.

- An alternative is that the lessor can terminate the lease when its own demand exceeds its remaining capacity. In this case, the lessor bears no risk and should charge a lower rate accordingly.

- The lessee simply acts as a referrer and take a fee when it hands over the customer to the lessor. The scheme is flexible to both parties. However, the difficulty lies in accounting because current service providers often adopt flat rate monthly plans.

Based on the performance metrics and service models, we plan to systematically analyze the performance of different decision-making strategies.

**Summary**  The FCC’s promotion on cognitive radio technologies and rulings on spectrum leasing in 2003 have shed light on improving spectrum efficiency and providing high quality wireless services. Most work has been focused on the design of cognitive radios while little attention has been given to the medium access control and networking layer, which is the focus of our research. This is a new and promising area, with great potentials to attract external fundings providing good preliminary results.