Weekly Report (2010-04-29)

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I. Electromagnetic Radiation and Human Body

Electromagnetic radiation can be harmful to human body when the frequency is above 100 KHZ while most of the wireless applications works on higher frequencies, e.g. cognitive radio (IEEE802.22: 54-72, 76-88, 174-216, 470-806 MHZ), WiMax (IEEE802.16: 2-66 GHZ), WiFi (IEEE802.11: 2.4-2.5 GHZ), 3G (about 900 - 1800 MHZ). In general, we have three classes of harmful radiation effects on human.

- **Thermal Effect**: Over 70% of human body is water. Electromagnetic radiation will cause friction among water molecules and increase the body temperature, which leads to the malfunction of human organs.
- **Non-thermal Effect**: Human body has a weak and steady electromagnetic field, which is in a balanced state. If electromagnetic radiation interrupts the balance, human body will be harmed.
- **Cumulative Effect**: Before the human body recovers from thermal and non-thermal effects with self-reparation, further electromagnetic radiation will cause cumulative damage, which may leads to permanent damage to human body. It may happen even under low-power and low-frequency radiation if we have a long exposure time.

The International Commission for Non-Ionizing Radiation Protection (ICNIRP), IEEE and several countries have set radiation standards for the sake of human body safety, as in table I.

Country or Organization	900 MHZ ($\mu w/cm^2$)	1800 MHZ ($\mu w/cm^2$)
China	40	40
ICNIRP	450	900
Hong Kong	450	900
Europe	450	900
Japan	600	1000
Australia	200	200
US FCC	600	1000
IEEE	600	1000

TABLE I: Public Radiation Standards.

They also provide radiation protection standards over a bandwidth. For example, Chinese GB8702-88 sets the radiation limit between 30 MHZ and 3 GHZ to be 40 mW/cm^2.

We can find that the radiation level is measured by $\mu w/cm^2$ or mW/cm^2. Then the following formula explains how to do the calculation.

$$\frac{P}{4\pi r^2}$$

Here, P is the transmission power and r is the distance to the antenna.

II. Potential problems

It is easy to see that the radiation is proportional to the transmission power, which should be minimized here. However, in order to provide guaranteed data service, the transmission power should be large enough.

- **Physical interference model**: we have to guarantee that the SINR value is above the threshold for a successful transmission. So we have

  $$\frac{P/d^\alpha}{N \times BW + I} \geq \beta$$

  Here, N is the noise density on frequency and BW is the bandwidth.

  A good power control algorithm should be designed such that the radiation is minimized while the network topology is connected and SINR requirement can be met.
- **Data rate**: the application may also require a minimum data rate, for example video streaming. According to Shannon's theorem, we have

  $$BW \log{(1 + \frac{P/d^\alpha}{N \times BW + I})} \geq R$$

  Here, R is the required data rate. In this case, besides the power control mechanism, we still need some spectrum management scheme.
- **QoS or BER**: the QoS or BER is also related with the SINR value in the form as follows,

  $$R\frac{P/d^\alpha}{N \times BW + I} \geq BER$$

So, we see that a tradeoff on radiation level and system performance should be made on the transmission power.

III. Cognitive Radio

Cognitive radio has some desirable features that can leverage the dilemma between radiation minimization and performance maximization.

- **Resource diversity**: Previously, all secondary users are contending for the scare resource of unlicensed channels. So, the interference among concurrent transmitters in the same channel can be very high, which have two consequences: (1) the number of concurrent transmitters is limited which leads to limited network capacity; (2) higher transmission power requirement to overcome the interference, which leads to even higher mutual interference. However, cognitive radio can assign the idle licensed channels to transmitter such that the resource diversity is increased. As a result, the interference in the same channel is decreased and so does the power requirement.
- **Channel bonding**: According to IEEE802.22, each channel has a bandwidth of 6 MHZ and contiguous channels can be bonded together as one channel. For example, the bandwidth between 350 MHZ and 380 MHZ is

available and can be bonded into one channel with bandwidth 30 MHZ. Recalling the formula for data rate calculation, increased BW can have increased data rate with constant P or have decreased P with constant data rate requirement.