Weekly Report (2010-05-10)

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I. Literature Study

A. Exposure in wireless sensor networks

The exposure of an object, e.g. human body, to wireless sensor networks is the generally defined as the probability for the sensor network to detect the object. It is usually calculated to examine the coverage of sensor networks. Suppose the object has a radiation power of P to the network, the exposure to sensor node i is a function $f(P/d_i^\alpha, N_i)$ with d_i as the distance between the object and sensor node i, α as the pass loss gain and N_i as the background noise at sensor node i.

In general, the objective is to maximize the minimal exposure such that the coverage of network can be maximized.

B. Laptop radiation

The radiation from the laptop is much larger than that from the access point. The transmission power of laptop with IEEE802.11 is between 2 mW and 100 mW with a typical value of 36 mW. But the transmission power of access point is generally below 100 mW. However, the transmission power can be amplified by the antenna by 3 dB or 6 dB, which means the power can be 200 mW or 400 mW (This is only applicable to directed antenna). Meanwhile, one access point may have multiple antennas transmitting on different channels.

II. Problem formulation

Key words: Multicast, Cooperation, Wireless MESH Networks, Software-defined Radio.

A. Motivation

In Fig. 1, there is only one access point and four wireless devices in the network. We have two options to conduct the multicast:

- **Broadcast**: The access point will broadcast the data to four nodes with maximum power $P = N_0 \cdot BW 2^{\alpha+1}$ in two channels. The overall data rate is limited by the achievable data rate for node b, which has the largest distance from the access point with *Shannon*'s theory
$$2 \times 2W \log{(1 + \frac{P/2^\alpha}{\eta \cdot W})}$$
- **Cooperative multicast**: The access point will transmit the data to a subset of the devices, e.g. node a, in one channel. Device a will forward the data to other devices in the other channel. So the network throughput is
$$2 \times W \log{(1 + \frac{P/1^\alpha}{\eta \cdot W})}$$

Since $\alpha > 2$, we have $2^{\alpha+1} > 8$.

$$
\begin{aligned}
& 4W \cdot \log\left(1 + \frac{P/2^\alpha}{\eta \cdot W}\right) - 2W \cdot \log\left(1 + \frac{P/1^\alpha}{\eta \cdot W}\right) \\
&= 2W \cdot \log \frac{(1+2)^2}{1+2^{\alpha+1}} < 0
\end{aligned}
$$

We see that cooperative multicast can increase the network throughput.

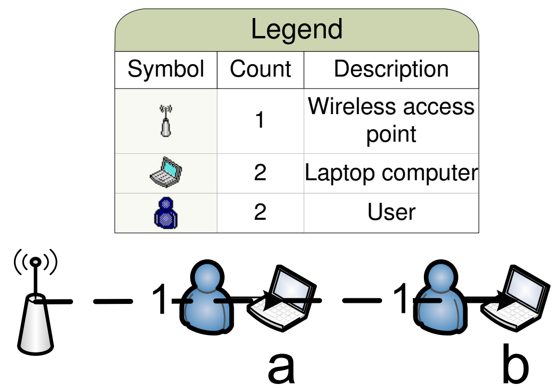

Fig. 1: Multicast with one access point.

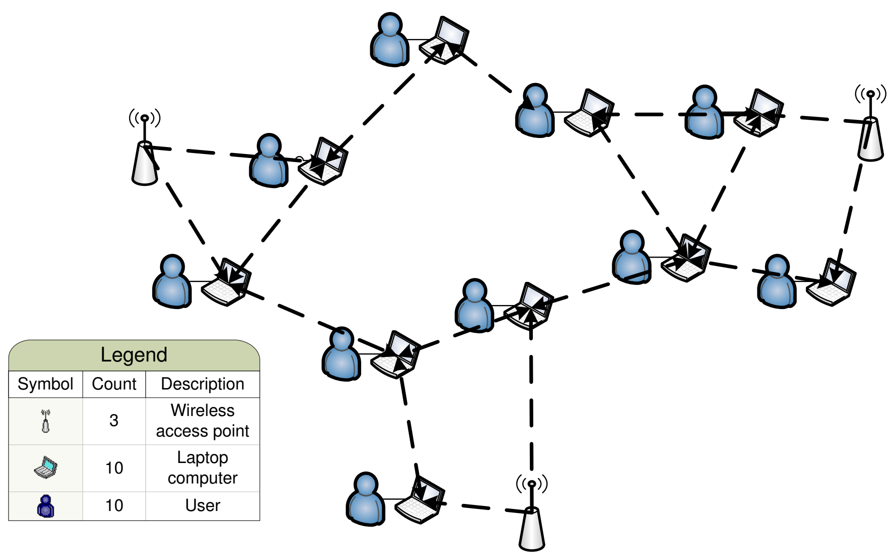

Fig. 2: Cooperative multicast with multiple access points.

B. Utility maximization problem

We consider the problem in a wireless MESH network with m stationary access points and n mobile wireless devices. Each access point or wireless device is equipped with C half-duplex antennas working on orthogonal channels. Only the radiation from the user's own device is taken into account while that from other devices and access points are ignorable. The direct communication between access point and wireless device has not fully exploit the potential network throughput. 1), the access point has limited channels, which means the wireless devices should share the channels in a TDM fashion; 2), there may be more available orthogonal channels in the air and software-defined radio can help to make use of these resources with opportunistic channel access and scheduling; 3), the wireless devices can construct a wireless ad-hoc network to conduct cooperative communication.

So we consider the utility maximization with cooperative multicast and software-defined radio.

- **Objectives**: Maximize the overall utility (e.g. throughput) of the network.
- **Constraints**: Cumulative radiation to each user; Mutual interference for transmitters in the same channel; Power consumption constraints; Routing in the network; Channel assignment.
- **Available information**: Maximum transmission power P_{AP} (P_{WD}) of access points (or wireless devices); matrix D characterizing the distance between each node pair; vector r indicating the distance between each user-device pair; vector μ indicating the tolerable radiation per unit area for each user;
- **Variables**: We need power control, e.g. vector P, and channel assignment, e.g. vector S, for both access points and wireless devices.

Fig. 2 gives an example of the proposed wireless network with cooperative multicast.

$$
\begin{aligned}
Maximize \quad & \sum_i U_i \\
s.t. \quad & \sum_{j,c} P_{ij}^c \leq 4\pi\mu_i r_i^2,\ \forall i \\
& P_{ij}^c \leq s_{ij}^c P_{WD},\ \forall i,j,c \\
& P_{hk}^c \leq s_{hk}^c P_{AP},\ \forall h,k,c \\
& \sum_j s_{ij}^c + \sum_j s_{ji}^c \leq 1,\ \forall i,c \\
& s_{ij}^c \beta_T \leq \frac{P_{ij}^c}{d_{ij}^\alpha},\ \forall i,j,c \\
& s_{ij}^c \beta_I + (1 - s_{ij}^c)\nu > \sum_{h \neq i, k \neq j} s_{hk}^c \frac{P_{hk}^c}{d_{hj}^\alpha},\ \forall i,j,c \\
& \sum_c \log\left(1 + SINR_{ij}^c\right) \leq \sum_{k \neq j, c} \log 1 + SINR_{ki}^c,\ \forall i,j
\end{aligned}
$$

The utility function U_i can be the absolute data receiving rate, which has $U_i = W \sum_{j,c} \log\left(1 + SINR_{ji}^c\right)$ with W as the bandwidth and $SINR_{ji}^c$ as the Signal-to-Interference-and-Noise-Ratio on channel c from node j to i, or weighted data rate for fairness of wireless device i.

The first constraint is that the overall transmission power of a wireless device on all channels cannot be larger than the radiation threshold, which is related to the user-device distance r_i and the upper bound of tolerable radiation per unit area μ_i.

The second and third constraints are that the transmission power on each channel of each wireless device (or access point) cannot exceed the maximum possible power P_{WD} (P_{AP}) on that channel of each wireless device (or access point). s_{ij}^c (s_{hk}^c) is a binary variable which indicates whether the device i (or access point h) is scheduled to transmit to device j or (k) on channel c : 1 if being scheduled while otherwise 0.

The fourth constraint is to avoid the primary interference on each channel of each wireless device such that one device cannot transmit and receive on the same channel simultaneously.

The fifth constraint is to ensure that the receiver should reside in the transmission range of the transmitter. Here, β_T is the SINR threshold for a successful transmission.

The sixth constraint is to guarantee that the receiver is out of the interference range of any other concurrent transmitter. Here, β_I is the SINR threshold for the interference and ν is a sufficient large constant.

The last constraint means that the total data transmission rate from node i to j cannot be larger than the overall data receiving rate at node i from other nodes. (*This constraint may not be accurate now*).

C. Possible extension

We may extend the problem with more features that can improve the network utility.

- **Network coding**: Since the wireless transmission is omnidirectional and each node in our example can serve as router for neighboring nodes, we can use network coding to further improve the network capacity.
- **Channel bonding**: In current problem model, we only consider channel assignment for each individual channel. As introduced previously, channel bonding technique may increase the network capacity while maintaining the radiation in a constant level.