Appendix - MISO Network

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Gaussian interference channels with relays are commonly employed to formulate the optimal control, power allocation or optimal scheduling problems of large-scale modern wireless networks [1–3]. An example network model with 3 transmitters, a single receiver and 2 relays is illustrated in Fig.17.

Given channel gains h_{ij} (i=1,2,3 and j=1,2), h_{Rk} (k=1,2), h_{lR} (l=1,2,3) in Fig.17, and the inputs to the transmitters x_1, x_2, x_3, the receiver output Y is given by the following equations:

$$Y_{R_1} = h_{11}x_1\mathbf{1}\{a_1 = 1\} + h_{21}x_2\mathbf{1}\{a_2 = 1\} + h_{31}x_3\mathbf{1}\{a_3 = 1\} + N(0, \sigma^2). \quad (1)$$

$$Y_{R_2} = h_{12}x_1\mathbf{1}\{a_1 = 2\} + h_{22}x_2\mathbf{1}\{a_2 = 2\} + h_{32}x_3\mathbf{1}\{a_3 = 2\} + N(0, \sigma^2). \quad (2)$$

$$Y = h_{R1}Y_{R_1} + h_{R2}Y_{R_2} + h_{1R}x_1\mathbf{1}\{a_1 = 0\} + h_{2R}x_2\mathbf{1}\{a_2 = 0\} + h_{3R}x_3\mathbf{1}\{a_3 = 0\}. \quad (3)$$

The individual state of the i^{th} transmitter at time t is defined as a tuple $s_{t,i} = (b_{t,i}, h_{t,i})$, where $b_{t,i}$ is the battery state and $h_{t,i}$ is the channel state with $b_{t,i} \in \{0, 1, ..., N-1\}$ $\forall i$. We define the battery probability transition tensor (PTT) of each transmitter $\mathbf{B}$ with dimensions $N \times N \times 3$, which stores the probability of transitioning between battery states under different actions. The structure of the battery PTT is similar to the buffer PTT except that there are now three actions. Then, the joint battery PTT $\bar{\mathbf{B}}$ is obtained as $\bar{\mathbf{B}} = \mathbf{B} \otimes \mathbf{B} \otimes \mathbf{B}$. On the other hand, the evolution of different channel gains is characterized by the standard (2-state) Gilbert-Elliot channel model with different probabilities as follows:

$$\begin{aligned} h_{11}, h_{12}, h_{21}, h_{22}, h_{31}, h_{32} &\in \{0, 1\} \text{ with } (p_1, q_1), \\ h_{1R}, h_{2R}, h_{3R} &\in \{0, 1\} \text{ with } (p_2, q_2), \\ h_{R1}, h_{R2} &\in \{0, 1\} \text{ with } (p_3, q_3), \end{aligned}$$

where p_1, p_2, p_3 are the probabilities of transitioning from state 0 (good) to 1 (bad), and q_1, q_2, q_3 are the probabilities of transitioning from state 1 (bad) to 0 (good). Different (p, q) can fully characterize the different channel gains. For example, the channel conditions between the transmitter and relay, as well as the relay and receiver are likely to be better than that of direct channel between the transmitter and receivers (due to shorter distance and less interference) Hence, we can assume that $p_1 = p_3 \ll p_2$ and $q_2 \ll q_1 = q_3$ (*i.e.* the channel is more likely to be bad for the direct channel). We then construct three channel transition probability matrices: $\mathbf{C}_1$, $\mathbf{C}_2$ and $\mathbf{C}_3$ for each three different distributions, and obtain the joint probability transition matrix $\bar{\mathbf{C}}$ as $\bar{\mathbf{C}} = \mathbf{C}_1 \otimes \mathbf{C}_2 \otimes \mathbf{C}_3$.

In the end, the probability transition tensor of the overall system $\mathbf{P}$ is obtained as $\mathbf{P} = \bar{\mathbf{B}} \otimes \bar{\mathbf{C}}$. The optimization problem is to choose optimal actions a_1, a_2, a_3 in order to minimize the overall cost function defined as follows:

$$\mathbf{c}(\{s_{t,i}\}_{i=1}^{3}) = -\alpha_1 Y + \alpha_2 \sum_{i=1}^{3}\sum_{j=1}^{2} x_i \mathbf{1}\{a_i = j\} + \alpha_3 \sum_{i=1}^{3}(1 - \frac{b_{t,i}}{N}), \quad (4)$$

where the first term is the negative throughput, the second term is the drop cost that balances the load on the relays (*i.e.* if multiple transmitters choose to use the same path through relay-1 or relay-2, there may be performance degradation), and the third term is the total amount of battery consumed (*i.e.* if $b_{t,i} = 0$, it means the battery is empty, and the corresponding cost is very large), with $\alpha_1, \alpha_2, \alpha_3$ being the weights.

For this setting, we use the following numerical parameters: $\sigma^2 = 1, x_1 = x_2 = x_3 = 1, p_1 = q_2 = p_3 = 0.2, q_1 = q_3 = p_2 = 0.8, \alpha_1 = \frac{1}{9}, \alpha_2 = \frac{1}{6}, \alpha_3 = \frac{1}{3}$. We also construct similar settings with different number of transmitters and relays using the same methodology given above. The network size is constructed in a similar way to that of the original wireless network model.

References

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