Calculation of Packet Success

The traffic messages from the probe vehicles are transmitted with a transmit power of P_i. When these messages arrive at a listening base station A they have experienced a power loss. An appropriate empirical model proposed by Egli in 1957 gives an area-mean power $\bar{p}_{A,i}$

$$\bar{p}_{A,i} = G_A \, P_i \, h_i^2 \, h_A^2 \, r_i^{-4} \left(\frac{40 \text{ MHz}}{f_c} \right)^2$$

where G_A is the antenna gain pattern of receiving base station A, h_i is the antenna height at probe i, h_A is the base station antenna height, r_i is the distance from transmitting probe vehicle to receiving base station and f_c is the carrier frequency.

Here, area-mean power is defined as the received power, averaged for an area of several tens of meters. It is generally accepted that the received power is further subject to shadowing and multipath fading. In this report, we ignore the effect of shadowing. Because of Rayleigh fading, the received power $p_{A,i}$ is an exponentially distributed random variable with mean $\bar{p}_{A,i}$.

A transmitted traffic message will only be received correctly at base station A if the received power $p_{A,i}$ is above a certain threshold. For an interference-free situation this probability of successful reception P_{NA} depends on the area-mean power $\bar{p}_{A,i}$ and the receiver noise floor, viz

$$P_{NA} = \mathbf{P}\left(p_{A,i} > z \, F \, k \, T_0 \, r_b\right) = \exp\left\{ - \frac{z \, F \, k \, T_0 \, r_b}{\bar{p}_{A,i}} \right\}$$

where z is the receiver threshold, i.e., the signal-to-noise ratio required for reliable communication, F is the man-made noise factor, kT_0 is a noise constant and r_b is the channel bit rate.

Slotted ALOHA

In slotted ALOHA, several traffic messages can be transmitted at the same time. This leads to mutual interference between messages. The probability that a traffic message from probe i, transmitted from road segment a_i at a distance r_i from receiving base station A

will be successfully received, can be written as the product of the probability of successful reception without interference, P_{NA}, and factor $P(A_i | r_i)$ accounting for the interfering traffic messages transmitted from all other road segments in the same time slot. We assume that this probability is equal and independent for all probes at segment a.
In our simulation approach, we continuously generate interfering probe vehicles. For N interferers, at distance r_1, ..., r_N the probability of successful reception of a test packa from probe vehicle i is

$$P(A_i | r_i, r_1, .., r_N) = P_{NA} \prod_{k=1}^{N} \frac{r_k^4}{r_k^4 + z r_i^4}$$

We further assume that the joint arrival process of interfering probe messages is a Poisson process.

In our analytical approach, the probability of successful reception $P(A_a | r_a)$ of a message from segment a in a noise-free environment can be shown to be

$$P(A_a | r_a) = P_{NA} \exp\left\{ - \sum_{\text{all links } i} \frac{z r_a^4}{z r_a^4 + r_i^4} G(i) \right\}$$

where r_a is the distance between road segment a and base station A and the parameter i indicates an index variable in the sum over all segments that cause interference. $G(i)$ is the mean number of traffic messages per time slot transmitted by the probe vehicles on road segment i. So the successful throughput, expressed in messages per unit of time from road segment a becomes

$$S(a) = G(a) \, \mathrm{P}(A_i | r_i, .., r_n)$$

for the simulation approach, and

$$S(a) = G(a) \, \mathrm{P}(A_a | r_a)$$

for the analytical approach.

Polling

In the demand or polling approach the process of transmitting probe vehicle messages is organized and controlled by the base stations. The advantage of this arrangement is that the probe vehicles in one base station cell transmit their messages in succession, so no mutual collisions will occur. Disadvantages are the more complex administration, additional polling messages and forfeit of privacy. Moreover, as a result of frequency re-use, polled probe transmissions still suffer from interference between messages in base station cells that use the same transmission frequency, the so-called co-channel cells.

Neglecting interference from co-channel cells as yet, the probability of successful reception of a traffic message transmitted according to the demand approach depends, just as in the supply approach in the case of an interference-free situation, only on the area-mean power $\bar{p}_{A,i}$ and the receiver noise floor and is computed in the same way, viz.

$$P_{NA} = \mathbf{P}\left(p_{A,i} > z F k T_0 r_b\right) = \exp\left\{ - \frac{z\ F\ k\ T_0\ r_b}{\bar{p}_{A,i}} \right\}$$

where z is the receiver threshold, i.e., the signal-to-noise ratio required for reliable communication, F is the man-made noise factor, kT_0 is a noise constant and r_b is the channel bit rate. The area-mean power $\bar{p}_{A,i}$ is given by Egli's model.

For N interfering co-channel cells at distance R_1, ..., R_N with omni-directional antennas at each base station, the probability of successful reception of a test package from probe vehicle i is

$$\mathbf{P}\left(A_i \,|\, r_i,\ R_1,..,R_N\right) = P_{NA} \prod_{k=1}^{N} \frac{R_k^4}{R_k^4 + z r_i^4}$$

where r_i is the distance from the transmitting probe vehicle to the listening base station.

The polling frequency of the probe vehicles within the cell of a particular base station is defined as the number of time slots between two successive transmissions of one and the same probe vehicle and is given by

$$f_p = \frac{f_s}{2\ C \sum_{a'} D(a') \ / \ P(A_i | r_i,\ R_1, .., \ R_N)}$$

where a' denotes all road links within the cell of the concerned base station, $D(a')$ is the number of probe vehicles on road link a' and f_s is the number of time slots per second preserved for uplink probe vehicle transmission or 'sampling rate'. The constant *2* reflects that each traffic message from a probe vehicle requires a polling message from the base station. The parameter C is the frequency re-use factor and incorporates the lengthening of each traffic message due to division of the available bandwidth into C portions.

So the successful throughput, expressed in messages per time slot from road segment a becomes

$$S(a) = f_p\ D(a)$$