Estimating average bit rate in wide-radio- frequency data communication system in presence of random failures

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In modern driverless automated mass transit underground rail systems, it is important for the operational control center (OCC) to be able to monitor passengers at all times, so that , in case of security problems (aggressive behaviour, fire, and so on), appropriate actions can be taken swiftly: contacting police, fire brigade, etc.
A wide-radio frequency trainborne network is used to convey image and sound data to the OCC.
Train-to-ground transmission is ensured by modems which communicate with trackside access points (APs). One modem is located at each end of a train and, in nominal mode, each modem communicates with a different AP. This permits a bit rate of 10 Mbit/s, which is necessary to guarantee suitable image definition.
However, in some operation scenarios (following the occurrence of an Emergency Brake), random modem failures can lead to degraded modes where remaining modems have to share an access point, in which case the bit rate goes down to 5 Mbit/s, or worse, communication is simply lost. Low bit rates no longer provides a suitable image definition and operational steps then have to be taken (for instance, passengers must alight at the next station). In case of complete communication loss, an emergency crew even has to be dispatched to the affected train, which can no longer be operated in driverless mode.
The problem raised by the train operating company is to estimate the frequency of such events, which are costly in terms of logistics and manpower.
The train designer’s concern is to verify that its design does not penalise operations excessively and to make recommendations on corrective maintenance measures to be taken following each failure (should the train complete its mission, should passengers be offloaded, etc.).

This question was addressed by ALSTOM in the following way.
In a first step, various degraded scenarios were identified, corresponding to the respective locations of trains at stations or between two stations: each of those situations leads to different reconfiguration patterns in case of failure.
In a second step, event trees were used in order to characterise the degraded states (in terms of bit rate) resulting from one or more failure.
Finally, a continuous-time Markov model was set up to describe the transitions from nominal mode to progressively degraded modes.
Solving the Markov model has allowed to assess the probability of losing the communication function or degrading it excessively.
In the course of a train mission, modem connections to access points reconfigure dynamically, therefore various configurations of connections are encountered, and each corresponds to a different Markov model.
In addition, attention had to be paid to the possibility of latent failures: normally, the modem used is the one located at the front-car of the train (in the direction of movement); in case of failure of that modem, the tail-end modem can be used instead (provided it has not failed since the latest turn-back of the train, i.e. since the last time it was itself the front–car modem). Accordingly, given the frequency of the various degraded modes, it is possible to provide the operator with an estimate of the average annual number of emergency actions of various kinds.
Sensitivity analysis with respect to the various parameters can also be performed.

The Markov model proves satisfactory but rests on the assumption that restoration time following a failure has an exponential distribution.
Additional accuracy would be gained by resorting to Petri net models and Monte Carlo simulation, which allows for arbitrary distributions.