A priority queueing model for the cognitive radio paradigm on a single channel

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Abstract

The goal of cognitive radio networking technologies is to recuperate the unused bandwidth in existing wireless telecommunication infrastructures. We consider a single channel on which licensed users (primary users, PU) can freely transmit packets, while the 'spectrum gaps' in between such transmissions can be used by packets from unlicensed users (secondary users, SU). Assuming Poisson arrivals, we derive the SU transmission and queueing delay distribution. In case of saturation with fixed-length SU packets, we also compute their throughput and probability of preemption by a PU transmission. Numerical investigations focus on the optimal SU packet length to maximise the throughput.

Keywords: cognitive radio, $M/G/1$ priority, throughput, optimal packet size

The new Cognitive Radio Networking paradigm for wireless communications [1] is inspired on the observation that although most of the frequency bands in the radio spectrum are licensed and reserved, they are for the most part heavily under-utilised. Hence, the idea is explored whether there is room in the licensed spectrum bands to accommodate unlicensed secondary users (SU) without disrupting the communications of the licensed primary users (PU). In order for this to work, the SU mobile devices need to be equipped with radio interfaces that have cognitive capabilities, i.e. they need to be able to detect spectrum usage in the environment and intelligently adapt their transmitting waveform accordingly. From the viewpoint of network throughput and incurred packet delay, these cognitive functionalities bring into play a number of complications that are currently addressed by the performance modelling community.

Assume some part of the wireless spectrum is divided in a number of frequency bands (channels) which are used by primary users to transmit packets on. A 'cognitive' agent transmits SU packets on the channel using so-called *opportunistic* scheduling. That is, if the channel is void of PU packets, a SU packet can be transmitted instead. However, since licensed users should not be impeded by secondary usage of the channel, any SU transmissions are immediately interrupted as soon as a PU packet enters the channel. We studied the maximal useful throughput of SU packets in a setting with multiple channels in [4], without considering the performance of the packet buffers. Preliminary work on a single-channel model has been done in [2] under some restrictive conditions.

We consider a continuous-time queueing model where packets from the PUs and SUs have generally distributed length and arrive according to a Poisson process with rates λ_1 and λ_2 respectively. Since the PU packets are impervious to the SU packets, opportunistic scheduling can be modelled by a preemptive $M/G/1$ priority queueing model, as was analysed in [3]. The analysis is based on the concept of *extended* SU service time c which in our application is the total transmission time of a SU packet, i.e. from the moment it first accesses the channel until it is received correctly. Note that during its transmission time, a SU packet can be interrupted (preempted) several times by PU busy periods and that each time the packet has to be retransmitted from the beginning, a behaviour which is labelled 'preemptive repeat-identical'. The model is extended to include a generally distributed *sensing period* at the start of each PU idle time, which is the time required by the agent to establish the fact that the channel is indeed vacant.

Expressions are obtained for the distribution of the number of queued SU packets, their transmission delay and their queueing delay. Of interest is also the probability ν that an ongoing SU transmission is interrupted by a PU, as well as the total number of times an SU packet is interrupted before it is successfully transmitted. The influence of the packet length distributions (of both PU and SU) and the distribution of the sensing period is investigated. Assuming the SU packets have a fixed length L, with header size H and useful payload $D = L - H$, it is shown that the SU throughput is very sensitive to the choice of L. Obviously, the question here is: given a certain demand of PUs on the channel, what is the optimal packet length L^* for the SU packets to maximise their useful throughput?

References

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