A Resource Queueing System for Performance Analysis of Integrated Sensing and Communication in 6G Networks

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Integrated Sensing and Communication (ISAC) is one of the enabling technologies of 6G, formalized in ITU-R Recommendation M.2160 as a new IMT-2030 usage scenario that allows a single infrastructure to simultaneously provide wireless connectivity and radar-like environment sensing. Rather than deploying separate hardware for communication and radar functions, ISAC reuses the same spectrum, antenna array, and RF front-end for both tasks, which reduces cost and spectral footprint but introduces a fundamentally new resource-sharing problem at the physical layer. Communication throughput scales logarithmically with the Signal-to-Interference-plus-Noise Ratio (SINR), whereas the lower bound on sensing accuracy – the Cramér–Rao Bound (CRB) – is inversely proportional to the Signal-to-Noise Ratio (SNR), so the two service types compete non-linearly for the same finite pool of transmit power, spectral bandwidth, and spatial degrees of freedom of the antenna array. This asymmetry means that classical queueing formulations built around identical, interchangeable servers do not directly apply, and motivates a resource-queueing formulation in which each request "consumes" a variable share of a shared budget rather than occupying a discrete server slot.

We consider a 5G NR base station operating in the FR2 band (28 GHz) that simultaneously serves up to K communication users and tracks up to M sensing targets. Communication requests and sensing tasks arrive as two independent Poisson streams, and their service times are modeled as independent exponential random variables, consistent with standard Markovian queueing assumptions. Propagation losses are drawn from distribution functions derived from the 3GPP TR 38.901 channel model: communication links use a one-way path-loss model, while sensing uses a two-way (round-trip) radar propagation model, since the signal must travel from the base station to the target and back, effectively doubling the attenuation exponent on the logarithmic distance scale.

A resource queueing system avoids tracking the individual path loss of every active user or target – a choice that would otherwise cause the state space to grow exponentially with the number of active requests. Instead, all path-loss randomness is aggregated into occupancy probabilities: the probability that the total resource demand of all currently active communication and sensing requests does not exceed the station's fixed power budget. Admission probabilities for a new request are then computed as the ratio between the occupancy probability of the state with one additional active request and the occupancy probability of the current state, and these ratios enter directly as state-dependent transition rates of a two-dimensional Markov process whose states are pairs (number of active communication users, number of active sensing targets). This construction keeps the state space compact – of order $K \times M$ rather than exponential in the number of users – while still capturing the coupling between the two traffic types through the shared resource budget.