SIC-based Massive Random Multiple Access: A Practical Approach

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***Abstract*—Massive random access is a fundamental challenge in modern wireless networks, particularly in the context of massive Machine-Type Communication (mMTC) and the Internet of Things (IoT). Machine-Type Communication (MTC) enables autonomous information exchange between devices, and serves as the core communication model for IoT systems. However, the primary challenge in MTC lies in the massive access of IoT devices to the shared wireless medium. The increasing demand for low-latency and scalable communication has driven the adoption of grant-free access schemes, which allow a large number of devices to transmit simultaneously without prior scheduling. Consequently, efficient collision management is crucial for maintaining high spectral efficiency, as the shared nature of the wireless medium leads to significant contention among devices [1].**

Successive Interference Cancellation (SIC)-based random access protocols have emerged as promising solutions toward resolving collisions effectively. SIC leverages the capture effect and advanced signal processing techniques to iteratively decode and remove interference from overlapping transmissions, increasing the likelihood of successful packet recovery.

In this work, we consider a network of n nodes transmitting update messages to a sink, referred to as the Base Station (BS). Backlogged nodes attempt transmission following one of two distinct SIC-based random access schemes, where the transmission probability and target Signal to Noise plus Interference Ratio (SNIR) are determined by the chosen scheme. Specifically, a backlogged node transmits with probability p and selects its modulation and coding scheme based on a target SNIR γ.

Assuming an Additive White Gaussian Noise (AWGN) communication channel, the target SNIR γ is linked to the achievable spectral efficiency η (bits per symbol) of the modulation and coding scheme, $\eta = \log_2(1+\gamma)$.

A packet is successfully decoded if its average SNIR at the BS meets or exceeds γ. Each node processes one message at a time, and while backlogged, it does not generate new arrivals. At the end of each time slot, a node learns whether its transmission was successful. If the transmission fails, the node reschedules and attempts retransmission until successful delivery. Once a message is successfully delivered, the node returns to the idle state.

We first introduce the Multi-Packet Reception (MPR) Adaptive Slotted Access (MASA) scheme, which establishes theoretical bounds on achievable spectral efficiency under an ideal SIC receiver in the described communication scenario. The SIC receiver model is detailed in [2]. MASA dynamically adjusts transmission probabilities and SNIR thresholds based on the number of backlogged nodes as follows. Given k backlogged nodes at the start of a slot, where $k_c \leq k \leq n$, the transmission probability and SNIR threshold are set as $p_k = 1$, and $\gamma_k = \frac{1}{a_\gamma k}$ respectively, where a_γ is a constant number. It has been shown that adopting these values of p and γ maximizes the achievable sum-rate (spectral efficiency) [3]. The asymptotic bounds for sum-rate are provided in [4].

Building on MPR Adaptive Slotted Access (MASA)'s theoretical framework, we propose a more practical approach to achieving these bounds via Frameless ALOHA (FA). The motivation for this approach stems from the challenges of realizing ideal SIC results in practice, as imperfect interference cancellation prevents achieving the theoretical gains of SIC fully.

FA extends these theoretical insights to a practical grant-free access scheme. Instead of predefined frame/slot durations, FA dynamically extends its contention period by adding slots until a stopping condition is met. Nodes transmit with probability, $p_a = \frac{\beta}{k}$, which scales inversely with backlog size to distribute transmissions across multiple slots, reducing collisions. The SNIR threshold is set to $\gamma = \gamma_{max}$. The BS employs SIC, first decoding singleton slots and then resolving multi-user slots via capture.

The stopping criterion in FA incorporates MASA's asymptotic analysis, more specifically the criterion are as follows:

1) **Number of Resolved Users: Until K_R number of users have been resolved, where $K_R \geq \alpha G_R$.**
   G_R is mean number of resolved packets, given k transmitted, i.e $G_R = \zeta(b)k$ [4]. In order to control how aggressively the resolution criterion is enforced, we define a parameter α, ranging from 0 to 1.

2) **Incremental Decoding Stopping Criterion: For small k, the number of resolved users requirement may become too strict or even impossible to meet, because there are not enough transmitted packets. To address this limitation, we define an incremental decoding stopping criteria. Instead of enforcing $K_R \geq \alpha G_R$ strictly, the base station continuously monitors the number of newly decoded packets after each slot. Let $\Delta G_R(t)$ represent the number of newly decoded packets in slot t. The contention period is terminated when:**

$$\Delta G_R(t) = \Delta G_R(t-1) = \cdots = \Delta G_R(t-\tau) \qquad (1)$$

   where τ represents the number of consecutive slots with no increase in decoded packets, after which the contention period is terminated.

The proposed FA methodology practically ensures the maximum achievable performance dictated by SIC-based decoding strategies.

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