Prioritised S-ALOHA

Conventional Slotted -ALOHA

- All nodes having a packet attempt transmission in a slot with certain probability.
- For fewer number of nodes, latency is lower and can be accepted for URLLC.
- **But** as number of nodes increases, the latency increases exponentially and system can't handle URLLC communication.
- One way to enable URLLC is to reserve dedicated resource for its transmission but it comes at the cost of *spectrum underutilization*.
- To alleviate this, *prioritised S-ALOHA* is proposed where both regular and URLLC packets are transmitted over same channel.

Overview

- Propose prioritized S-ALOHA to achieve target reliability for URLLC.
- Analyse proposed protocol using Discerte Time Markov Chain Formulation.
- Obtain and Study delay distributions for regular and URLLC packets.
- Form optimization problem that maximizes regular performance while ensuring QoS for URLLC.
- Compare performance of proposed protocol with CS-ALOHA and Diversity Transmission (DT) Scheme.
- In DT, the same data is sent multiple times to improve reliability.

Terminology

- Nodes
- Channel
- Single Hop Communication
- Packet
- Base Station
- Uplink/Downlink
- UC?
- Markov Chain
- ALOHA?

Model Assumptions

- Packet transmission is successful only when a single node transmits a packet in a slot. That is, collision is not allowed.
- At end of each time slot, nodes obtain immediate feedback of successful or failed transmission. This is possible due to single hop communication.
- If there's a packet waiting for transmission at a node, no new packets can arrive at that node, hence no buffering.

System Model

- A single cell uplink scenario with multiple nodes connected to single BS.
- Packets can be either regular or URLLC and a node can generate one type of packet at a time.
- Time is considered slotted with each slot having duration of τ units.
- Packets arrive at a given node following Geometric Distribution.
- Deferred First Transmission (DFT) mode of S-ALOHA is considered where a new arriving packet joins the backlog nodes and packets are transmitted with a probability in each slot.

Prioritized S-ALOHA

- Each node having a backlogged packet transmits with a certain probability at the start of a slot.
- Since URLLC packets must be prioritized, they have a higher probability.
- Reliability Definition: .....
- By analysing the reliabilities of both packet transmissions, the optimal packet transmission probabilities are obtained such that performance is maximized while the URLLC QoS is met.

Protocol Analysis

Property	Regular Packets	URLLC Packets
Packet Arrival Rate	λ_r	λ_u
Packet Generated by Nodes	N_r	N_u
Packet Transmission Probability	P_r	P_u
Number of backlogged nodes transmitting packets	X_r	X_u
Probability of successful transmission of packet for given backlogged nodes	$\alpha_r(x_r,x_u)$	$\alpha_u(x_r,x_u)$
Probability of new packet arrival given backlog nodes at w packet nodes of same type	$\beta_r(x_r,w)$	$\beta_u(x_u,w)$

Protocol Analysis (contd...)

- Considering memoryless nature of packet generation and transmission, a two-dimensional Markov Chain with states denoted as $n(t) = (x_r, x_u)$ at time t.
- Total number of states in this markov chain is $(N_r+1)(N_u+1)$.
- For the one-step state change from (x_r,x_u) to (y_r,y_u), the transition probability for the markov chain is given by $p(x_r,x_u,y_r,y_u)$.
- The probabilities of successful transmissions are given by:

$$\alpha_r(x_r, x_u) = x_r p_r (1 - p_r)^{(x_r - 1)} (1 - p_u)^{x_u}$$
$$\alpha_u(x_r, x_u) = x_u p_u (1 - p_u)^{(x_u - 1)} (1 - p_r)^{x_r}$$

- Similarly, probabilities of new packet arrivals are given by:

$$\beta_r(x_r, w) = {}^{N_r - x_r}C_w \ \lambda_r^w \ (1 - \lambda_r)^{N_r - x_r - w}$$
$$\beta_u(x_u, w) = {}^{N_u - x_u}C_w \ \lambda_u^w \ (1 - \lambda_u)^{N_u - x_u - w}$$

One-Step Transition Probability

This can be divided into four cases:

1. When both nodes successfully transmit in a single slot i.e. $y_r = x_r$-1 and $y_u = x_u$-1. But this is not possible as that's a collision and violation of our assumption.

2. When one regular packet backlog node has transmitted and y_u-x_u new URLLC packets are generated and in backlog i.e. $y_r = x_r - 1$ and $y_u - x_u > 0$. Here
$$p = \alpha_r(x_r,x_u)\ \beta_u(x_u,y_u-x_u)\ \beta_r(x_r,0)$$

3. Similarly, when one URLLC packet backlog node has transmitted
$$p = \alpha_u(x_r,x_u)\ \beta_r(x_r,y_r-x_r)\ \beta_u(x_u,0)$$

One-Step Transition Probability

And the final case when y_u-x_u > 0 and y_r-x_r > 0 is subdivided into three parts:

i. A regular packet is successfully transmitted: $p_1 = \alpha_r(x_r,x_u)\ \beta_u(x_u,y_u-x_u)\ \beta_r(x_r,y_r-x_r+1)$

ii. A URLLC packet is successfully transmitted: $p_2 = \alpha_u(x_r,x_u)\ \beta_r(x_r,y_r-x_r)\ \beta_u(x_u,y_u-x_u+1)$

iii. None of the packets are successfully transmitted:

$$p_3 = [1-\alpha_r(x_r,x_u)\alpha_u(x_r,x_u)]\ \ \beta_r(x_r,y_r-x_r)\ \beta_u(x_u,y_u-x_u)$$

From the transition probability matrix, steady state probability of being in a state (π(xr,xu)) is given by $\pi = \pi p_r$.