# Power Levels and Packet Lengths in Random Multiple Access with Multi-packet Reception Capability

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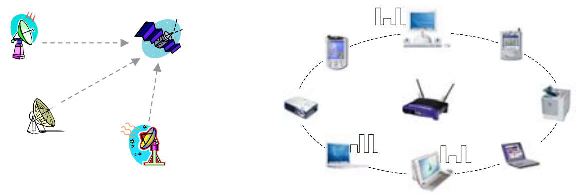
## Background

The idea of using multiple power levels in random multiple access have been proposed, for many years, to take the advantage of power capture in wireless networks.

## Abstract

With a high transmission power, the SINR requirement can be satisfied with a short packet length. Taking this into consideration, we proved that, the conventional single power level system is optimal when the SINR threshold is above 3.44. This conclusion holds even when the receiver has multi-packet reception capability.

## System Model and Major Assumptions

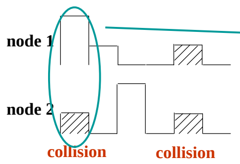


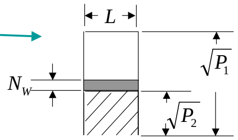
1. One receiver, several transmitters.
2. Random multiple access.
3. Slotted ALOHA for packets with the same length.
4. Maximum power bound.
5. Poisson traffic.
6. Fixed number of symbols per packet.
7. If not received successfully, packets will be retransmitted at a later time.
8. To be received successfully, the SINR of a packet must be above a threshold $T$.
9. Assume packets choose their power levels randomly with pre-designed probabilities.
10. Equal distance (transmission power ⇔ receiving power).
11. BPSK modulation, no coding, constant power during the transmission of each packet.

Assumed to simplify the analysis.

## Conventional Multiple Power Level Idea

High power packet may still satisfy the SINR requirement, and hence may survive the collision.

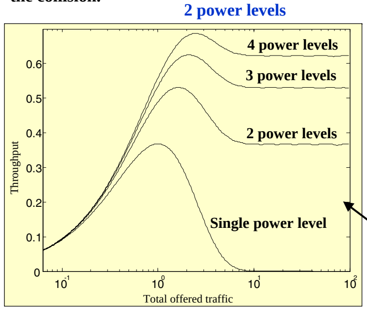



$$SINR_1 = \frac{P_1 L}{P_2 L + N_W} \geq T$$

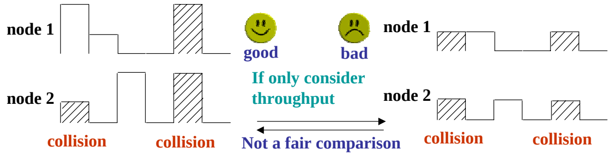
$$SINR = \frac{P_{min} L}{N_W} \geq T$$

- $N_W$ : Noise spectral density
- $L$ : Packet length
- $P$ : Transmission power
- $T$ : SINR threshold

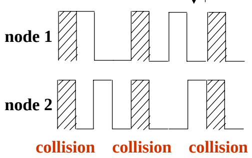



If the packet length of the systems are identical, using multiple power levels increases the overall system throughput

## Power Levels and Packet Lengths




Which one is good ?




high power ⇒ SINR requirement can be satisfied with shorter packet length

shorter packet length ⇒ more slots per second

more slots per second ⇒ higher throughput ?

Consider bandwidth limit, assume

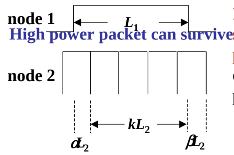
$P_{max} L_{min} \leq T N_W$

Since we allow the change of packet length, there are many possible designs of the multiple power level system. The following receiver model shows what kind of multiple power level systems are considered.

## Receiver Model

Packet received successfully, if and only if $SINR \geq T$ throughout the packet transmission period.

Packets of the same length are transmitted in slotted ALOHA.

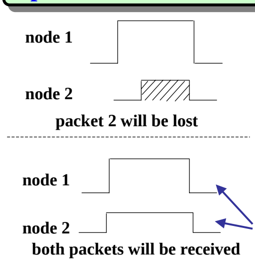



High power packet can survive

If packet 1 overlaps with packet 2, at least one symbol of packet 1 is covered by symbols from packet 2. The left figure illustrated a situation when one symbol of packet 1 is covered by the symbols of packet 2.

$$SINR_1 = \frac{P_1 L_1^2}{(k + \alpha^2 + \beta^2) P_2 L_2^2 + N_W L_1}$$

## Optimistic Receiver Model (used in the proof)




Packets of power level $P_2$ is lost only when

$P_2 < P_1$ and $L_2 < L_1$

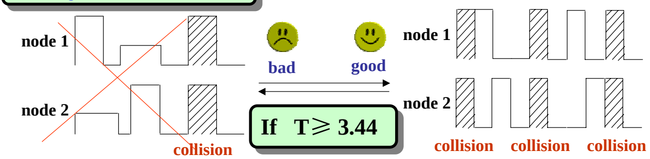
In all other situations, $P_1$ is received successfully no matter how many packets of $P_2$ exists.

$P_2$ is also received successfully no matter how many packets of $P_1$ exists.

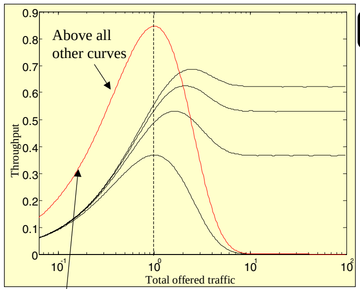
## Allows Multiple Packet Reception

## Major Conclusion

Optimal single power level system is preferred




If $T \geq 3.44$




Effect of short packet length on the system throughput.

## Single Power Level System

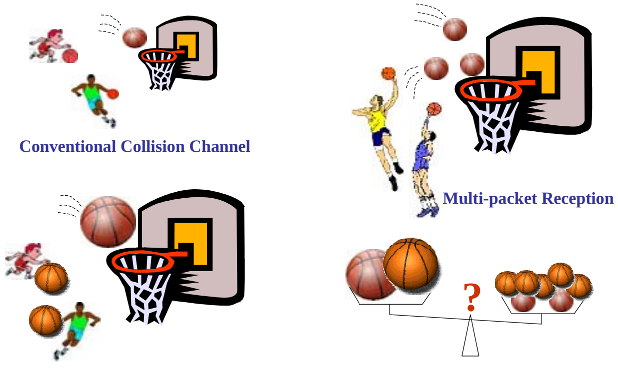
- Achieves highest throughput (received packets /second)
- Given a throughput lower bound Achieves highest packet capture probability
- Given a throughput lower bound Achieves highest power efficiency

$$\text{Throughput} = \frac{\text{\# of received packets}}{\text{second}}$$

$$\text{Packet capture probability} = \frac{\text{throughput}}{\text{\# of offered traffic per second}}$$

$$\text{Energy efficiency} = \frac{\text{throughput}}{\text{average transmission energy per second}}$$

## Further Considerations on Multiple Packet Reception




Multiple packet reception does not come without cost. For a fair comparison between a multiple packet reception system and a single packet reception system, both systems should be optimized in the sense that they use the system resources efficiently. Under such constraint, which system is better is not a trivial question. Even if the multiple packet reception is feasible in certain practical situations, the optimal design of the system still requires further research effort.

## Conclusion

We considered systems with multiple power levels and multi-packet reception capability in random multiple access. We proved that the single power level system where users transmit with the highest transmission power and a short packet length achieves the highest system throughput, when the SINR threshold ≥3.44. Given a minimum throughput constraint, the single power level system achieves the highest packet capture probability and the highest energy efficiency. In other words, even when the receiver does have multiple packet reception capability, single packet reception is still preferred.

The results also show that multi-packet reception is not always good. Our current research is focused on related system design considerations.