Multidimensional PRMA with Prioritized Bayesian Broadcast

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Motivation

- To effectively utilize the system resources defined over both code and time domain UTRA TDD.
- Effectively multiplexing bursty data traffic sources with packetized voice by means of packet switching.

3G

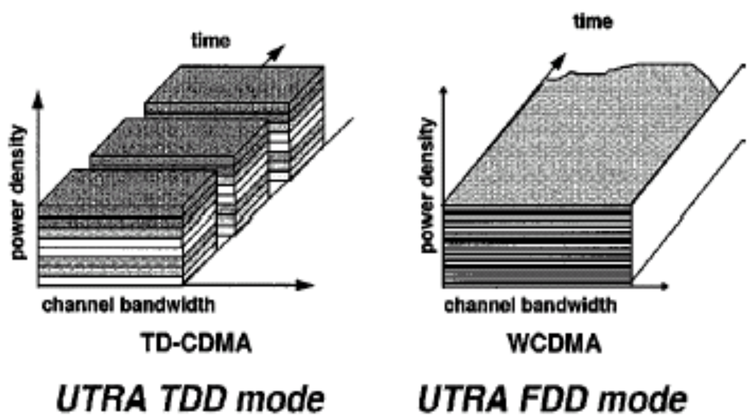
- There are three mode of operations in the Global Third Generation concept
  - CDMA-DS based on UTRA FDD (WCDMA), a pair of 5 MHz bandwidth for uplink and downlink – 3GPP
  - CDMA-MC based on cdma2000 – 3GPP2
  - CDMA TDD based on UTRA TDD (TD-CDMA) – 3GPP

3G

- UTRA FDD – suitable for public macro and microcell environments, supports up to 384 kb/s

- UTRA TDD – suitable for public micro and picocell environments, supports upt 2 Mb/s [2].

3G



PRMA

- Packet Reservation Multiple Access proposed as a MAC protocol for uplink microcellular packet switching communication [3].
- U time slots of fixed length are grouped into frame.

PRMA

- It consists of C (contention) slots and I (reserved or idle) slots.
- BS indicates on the down link whether it is C or I slot.
- When there is a packet spurt, a terminal send a request to transmit a packet on the next C slot with a permission probability p.

PRMA

- Upon successful request (no collision), BS send ACK (no delay) to inform the reservation or this slot (becomes I slot), a terminal enjoys uncontested access for the remainder of the spurt
- If the request is negative, a contention procedure is repeated.
- For delay sensitive but loss insensitive such as voice, a terminal drops packets if the contention takes longer than a delay threshold Dmax.

PRMA

- For data, there is no reservation. Data terminals must contend for the access every time they have packets to transmits. (optionally with limited reservation duration)
- Periodic terminal releases the reserved slot after it completes the transmission of packet spurt.

MD-PRMA

- Add code dimension by subdividing the time slots into Q code subslots (slots).
- Scheme A: select any on of the multiple C slots with equal likelihood.
- Account for the propagation delay by prohibiting the contention in the next x time slots after the first request.
- x must be less than U.

MD-PRMA

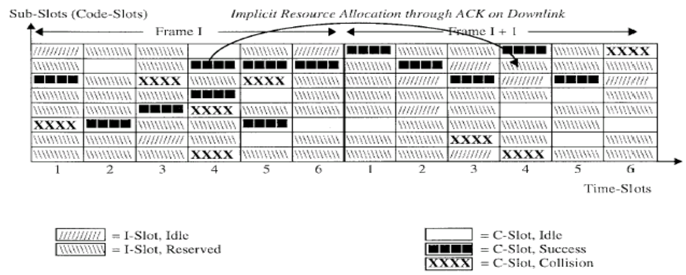


Fig. 2. Slots and frames in MD PRMA.

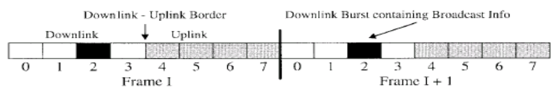


Fig. 3. Organization of uplink and downlink slots in TDD mode.

MD-PRMA

- Scheme B subtracts the request header after successfully access the channel.
- Employ interleaving and the depth of interleave equals the voice frame duration Dvf = Dmax. Dropping occurs framewise rather than packetwise.
- In scheme C, BS sends ACK only at the end of TDMA frame. Mobiles are allowed to contend repeatedly on C slots, and to send a request at most one per time slot. If BS receives multiple requests, BS ACKs only the first one.

Assumptions

- Q = 8 (SF = 8), use OVSF.
- Perfect Collision Channel (no capture)
- Assume Gaussian approximation to account MAI on top of code collisions.
- Ignore Joint Detection (suppress intracell interference
- Each burst fits into one slot
- BS broadcasts slot info in a particular TDMA frame.

Assumptions

- Voice Model: (exponentially distributed)
  - voice only: mean spurt = 1.41 s, mean gap = 174 s.
  - mixed traffic: mean spurt = mean gap = 3 s.
- WWW Model:
  - Data session follows Poisson process
  - A session consists of several packet calls
  - A number of packet calls per session is geometrically distributed with mean = 5 and the duration between each packet call is exponentially distributed with mean = 4 s.

Assumptions

- WWW model:
  - A number of packet per each packet calls is geometrically distributed with mean = 25 and the duration between each packet is exponentially distributed with mean = 0.5 s.
  - Packet size (bytes) follows the truncated Pareto distribution with a mean of 481 bytes
- Email model:
  - A single e-mail is generated per session
  - Ignore e-mails larger than 500 Kbytes to compromise between large mean (27 kbytes) and small mode (1600 – 1800 bytes).
  - As a result, e-mail size also follows the truncated Pareto distribution with a mean of 9423 bytes with a mode = 1400 bytes.

Bayesian Broadcast in Slotted Aloha

- Deferred First Transmission (DFT), every terminal with a packet spurt to transmit is considered a backlog including those collision terminals waiting for a new contention.
- Estimate the probability of number of backlogged stations using Bayes's rule and observe the history of collisions, successful transmissions, and empty slots [4].
- Calculate the probability of transmission accordingly.

Pseudo Bayesian Broadcast

- Use Poisson distribution to estimate the mean number of backlogs – v.
- Probability of transmission p = 1/v
- Algorithm,
  - At t = 0, set v = 1
  - p = 1/v
  - if slot = idle or success, v = v – 1 else (collision) v = v + 1/(e-2)
  - v = max(v + lambda, 1), lambda is the arrival rate of new packets per slot
  - lambda = $R_{avg}/e + MD_{slot}/(D_{spurt} + D_{gap})$

Bayesian Broadcast for MD-PRMA scheme A

- R = Q (codes), estimate backlog per slot = v/R (v = mean total back backlogs on a time slot)
- Not every R is available for contention (C slots), it varies from time slot to time slot R[t].
- BS broadcasts the updated p at the end of each time slot to all mobiles.

Bayesian Broadcast for MD-PRMA scheme A

- Algorithm: R[t] denotes the number of available contention slots in time slot t
- Assume immediate ACK
  - At t = 0, v = R[t]
  - p = min(1, R[t]/v)
  - If the number of collisions = C, v = C/(e-2) – (R[t]-C)
  - v = max(v + lambda, R[t])

Bayesian Broadcast for MD-PRMA scheme A

- With delay x < U scheme,
- The expected number of backlogs
  - w = 2.3922C_x
  - C_x is the number of collisions observed in the last x time slots
- if w > v -1 then w = v – 1,
  - p = min(R[t]/(v-w), 1)

Bayesian Broadcast for MD-PRMA scheme C

- Algorithms:
  - At t = 0, v = v' = 1
  - p = min(R[t]/v, 1)
  - v' = v' + C/(e-2) – (R[t] – C)
  - if t+1 is in the same frame as t, v' = v' + lambda go to 2, otherwise go to 5
  - v = v' = max(v' + lambda + s'', + 1)
- s'' is the number of received contention packets except the first one of each MS
- BS broadcasts p and v per frame together with the slot status

Prioritization

- Allow calculation of multiple pi per time slot to discriminate QoS of different service classes.
- Si is the C slot throughput
- p1 has the highest priority
- k= 1, same priority, k < 1, different pi value increases, the spread of access delay values follows

$$p_1 = \min(1, m \cdot p) \quad (10)$$

$$p_2 = \min\left(1, \frac{z_1 m + z_2 k}{z} p\right) \quad (11)$$

$$p_3 = \min\left(1, \frac{z_2 m + z_1 k}{z} p\right) \quad (12)$$

$$p_4 = k \cdot p \quad (13)$$

with

$$m = \frac{1 - \alpha \cdot k}{1 - \alpha} \quad (14)$$

$$z = z_1 + z_2 \quad (15)$$

and

$$\alpha = \left(\frac{z_2}{z} S_2 + \frac{z_1}{z_2} S_3 + S_4\right) \frac{1}{S} \quad (16)$$

Results

- BB offers stable operation under high load and low packet dropping at low load.
- ACK delay x in scheme A causes the algorithm longer time to adapt to the collision resulting higher packet dropping

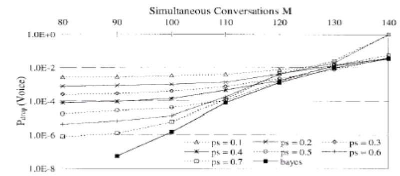


Fig. 5. Bayesian broadcast versus fixed p_s with immediate acknowledgment.

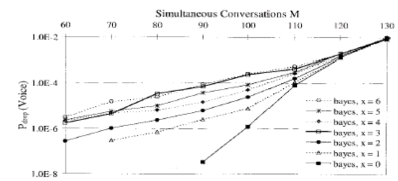


Fig. 6. Impact of acknowledgment delay on Bayesian broadcast (x = number of forbidden time slots after contention).

Results

- Performance for scheme A, B, C shows little differences.
- Increasing packet dropping delay threshold is compensated by the interleaving in scheme B.
- Scheme C shows resistant to ACK delays.

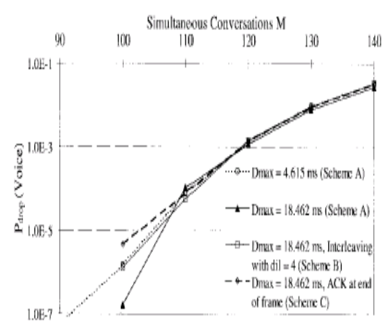


Fig. 8. Performance comparison of MD PRMA with (Scheme B) and without interleaving (Scheme A) and MD FRMA in FDD mode (eight uplink slots, Scheme C).

Results

- Mixed traffic shows little influence on voice packet dropping.
- Prioritization does not effect the access delay as desired.
- S = 0.76 corresponds to 8% data traffic and S = 0.95 corresponds to 27%

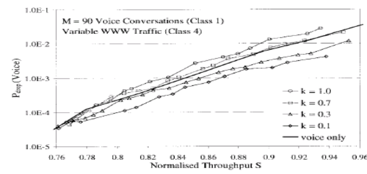


Fig. 10. Voice-dropping performance with mixed voice and WWW data traffic.

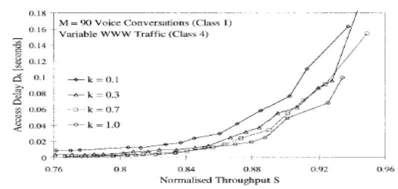


Fig. 11. Delay performance of data with mixed voice and WWW data traffic.

Results

- With unlimited allocation cycle, different k has no impact on P_{drop}.
- Limited allocation cycle improves P_{drop} but at the expenses of extra delay for data traffic

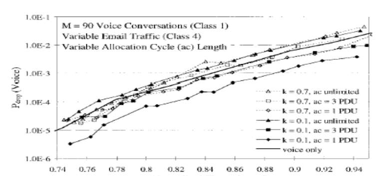


Fig. 12. Voice-dropping performance with mixed voice and e-mail traffic, variable allocation cycle length (in terms of long PDU's per cycle).

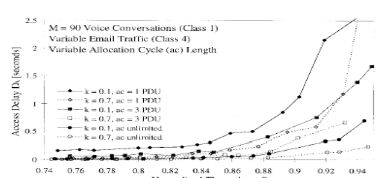


Fig. 13. Mixed voice and e-mail data traffic, access delay of data (cumulative in case of limited allocation cycles, i.e., total time spent in contention state).

Results

- P_{drop} is worse since data is assigned to access classes 2 to 4
- Access delay is noticeable with small k (0.1).
- Depending on k and allocation cycles, a desired control of prioritization is achieved with a good trade-off between voice-dropping and data-access delay

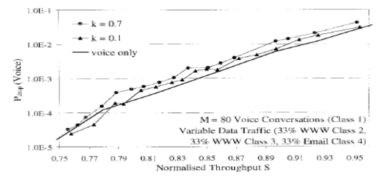


Fig. 14. Voice-dropping performance with mixed voice, WWW, and e-mail data traffic.

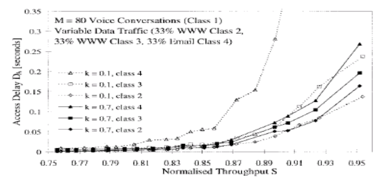


Fig. 15. Access delay performance of data with mixed voice, WWW, and e-mail data traffic.

Results

- MAI increases burst loss (Pber)
- M < 130, P_{ber} is dominant over P_{drop}
- Use load-based access heuristic,
  - $p = \min(p_{max}, R[t]/v)$
  - $p_{max} = \min(1, 2^{R[t]-1}.l)$
- Optimize l to compromise between P_{ber} aand P_{drop}

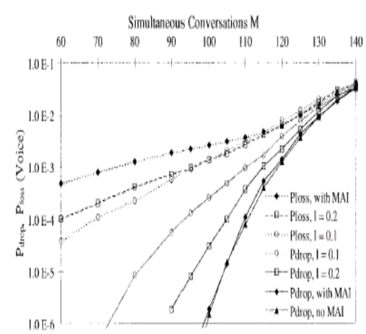


Fig. 16. Voice packet dropping and loss probabilities with and without MAI using Bayesian broadcast, with MAI also combining Bayesian broadcast with load-based access control with $l = 0.1$ and $l = 0.2$.

Conclusion

- MAC algorithm for UTRA TDD is proposed.
- Using Bayesian Broadcast with MD-PRMA improves voice packet dropping performance.
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- Introducing prioritization to achieve good performance with mixed traffic classes.
- No implementation of multicodes to support high data rate.
- Preclude BER requirement for different traffic classes.

References

- [1] A. E. Brand and A. H. Aghvami, "Multidimensional PRMA with Prioritized Bayesian Broadcast – A MAC Strategy for Multiservice Traffic over UMTS," IEEE Transactions on Vehicular Technology, vol. 47, no. 4, Nov. 1998.
- [2] M. Haardt et al., "The TD-CDMA Based UTRA TDD Mode," IEEE JSAC, vol. 18, no. 8, Aug. 2000.
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- [4] D. J. Goodman et al., "Packet Reservation Multiple Access for Local Wireless Communications," IEEE Transactions on Communications, vol. 37, no. 8, Aug. 1989.