Access Control for Voice/Data CDMA

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Integrated Voice/Data CDMA System

Voice rates $R_v$
Intolerant to delays
Can tolerate occasional errors

Data rates $R_d$
Tolerant to moderate delays
Error intolerant

DS-CDMA, bandwidth $W$

Slotted reverse link
Voice and Data users sharing system resources

- CDMA Systems are interference limited
Design criteria for access control

Outage Probability $\leq 1\%$

Minimum data rate throughput for data users

Average data rate throughput for data users

System capacity maximization
Main Causes for Outage

- Imperfections in estimating the residual capacity
- Imperfections in scheduling the desired number of data users
- Imperfections in power control

Goal: Eliminate first listed cause for outage!
Design steps for the access control protocol

Define outage condition (maps FER requirements)

Derive ideal residual capacity expression

Obtain an estimate for the number of data users which are allowed to transmit in the next time slot

Employ an access procedure to allow the exact predetermined number of data users to transmit in the next time slot
Perfect Power Control - Power Control Feasibility condition:

\[ S(n) = \frac{\nu(n)}{a_v} + \frac{d(n)}{a_d} \leq 1 - \delta \]

\[ S(n) = \text{normalized load in the } n^{th} \text{ time slot;} \]

\[ \nu(n) \text{ and } d(n) = \# \text{ of active voice and data users;} \]

\[ a_i = \frac{W}{R_i \gamma_i + 1} \quad \delta = 0.001 \]

\[ \gamma_i = \text{target SIR for voice/data;} \]

Outage: when \( S(n) > 1 \)
Residual Capacity

\[ d(n) = \max \text{ # of data users in the system s.t.} \]

\[ S(n) \leq 1 - \delta \]

\[ d(n) = a_d (1 - \delta) - \frac{a_d}{a_v} v(n) \]

Problem: \( v(n) \) - random variable \( \Rightarrow d(n) \) - random variable \( \Rightarrow \) only an estimate \( \hat{d}(n) = \func(v(n-1)) \) can be derived

\( \hat{d}(n) \) - integer number \( \Rightarrow \) only \( \lfloor \hat{d}(n) \rfloor \) data users can be scheduled for the next time slot
Delta Modulation approximation for residual capacity
Delta Modulation approximation for residual capacity

Accuracy of approximation:
- sampling frequency $f_s$
- step of modulation $\Delta$

Two types of distortions:
- granular noise
- slope overload distortion

Condition for no slope overload distortion:
$$|s(t)| \leq \Delta \cdot f_s$$

Additional Constraint:
$$\hat{s}(n) \leq s(n)$$
Steps of MDM algorithm:
- first time slot: measure number of active voice users and initialize $\hat{d}_t(1) = d_t(1)$
- for $n > 1$: if $\hat{d}_t(n - 1) > d_t(n - 1)$, then set $\hat{d}_t(n) = \hat{d}_t(n - 1) - \Delta$
  if $\hat{d}_t(n - 1) < d_t(n - 1)$, then set $\hat{d}_t(n) = \hat{d}_t(n - 1) + \Delta$
  if $\hat{d}_t(n - 1) = d_t(n - 1)$, then set $\hat{d}_t(n) = \hat{d}_t(n - 1)$

Function to be approximated ($d_t$) versus approximation. Imperfect Power Control
Introduce guard margin = step of the modulation ($\Delta$) – the function to be approximated becomes:

$$d_i(n) = d(n) - \Delta$$
no slope overload condition \[ |s(t)| \leq \Delta \cdot f_s \]

Max. # of data users allowable in the system at each time slot

\[ d(n) = a_d (1 - \delta) - \frac{a_d}{a_v} v(n) \]

cumulative voice activity process - discrete Markov chain (the slot duration very small such that at most \( \pm 1 \) change in the number of active voice users can occur)

choose \[ \Delta = \frac{a_d}{a_v} \]
MDM-S (Modified Delta Modulation with Scheduled Access)
- exactly $\hat{d}(n)$ users are scheduled to transmit in the next time slot in a round-robin fashion
- no outage due to the access control

MDM-R (Modified Delta Modulation with Random Access)
- access probability (ML estimate) - max. prob. that exactly $\hat{d}(n)$ users will transmit in the next time slot
- a probability tolerance value is defined to allow the fine tuning of system performance
Fixed # of admitted data calls ($K_d$):

$$p(n) = \frac{[\hat{d}(n)] - t_p}{K_d}$$

**SMS:** Poisson arrival for data with rate $\rho$:

$$p(n) = \frac{[\hat{d}(n)] - t_p}{\rho}$$

- rate of admitted data traffic:

$$\rho_a(n) = \rho p(n) = [\hat{d}(n)] - t_p$$
Outage Condition: limited interference

\[ Z(n) = \frac{1}{G_v} \sum_{i=0}^{K_v} v_i(n) \epsilon_i^v + \frac{1}{G_d} \sum_{i=0}^{K_d} \zeta_i(n) \epsilon_i^d \leq (1 - \eta) \]

\[ Z(n) = \text{load; } v_i(n) \text{ and } \zeta_i(n) \text{ voice and data activity indicators} \]
\[ \epsilon_i^v, \epsilon_i^d = \text{SIRs for voice/data;} \]
\[ \frac{1}{\eta} = \text{maximum allowed received PSD to background noise PSD} \]

\[ P_{out|v(n),d(n)} = P\{Z > (1 - \eta) | v(n), d(n)\} = Q\left(\frac{(1 - \eta) - E(Z)}{\sqrt{\text{var}(Z)}}\right) \leq 0.01 \]
Numerical Results for Perfect Power Control


- MDM-R. Analysis: $t=0$
- MDM-R. Simulations: $t=0$
- MDM-R. Analysis: $t=2$
- MDM-R. Simulations: $t=2$
- Pers. state alg. Sim., $K=5$. 

$K_d$ (number of data users) $\rightarrow$

$\%$ Gain $\rightarrow$
Numerical Results for Imperfect Power Control

Outage Probability. Imperfect Power Control. $K_v = 10$

Bidimensional Capacity for a range of mean access delays
Optimal Operating Points

Admission Control. Allowable system operating points \( \{ K_v^*, K_d^* \} \)

Imperfect power control. Mean access delay \( D_a = 0.6 \). Scheduling

Legend:
- optimal operating points
- restricted region
- allowable region
Two access control schemes are proposed and the performance is compared with earlier work (WINLAB TR - 127, TR-143)

- Both schemes give better performance
- MDM-R - very efficient implementation
- MDM-S - guarantees zero outage for the perfect power control case

Two data models are considered in the analysis:

- Non-transparent data service (ftp, mail, store and forward facsimile) - WINLAB TR- 172
- Short Message Service (Poisson arrivals for data; only open loop power control for data) - WINLAB TR in preparation