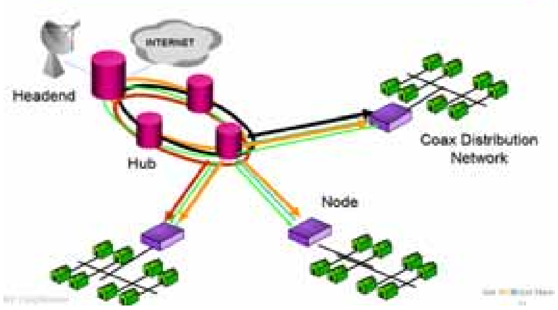
Optimal Ranging Algorithms for Medium Access Control in Hybrid Fiber Coax Networks

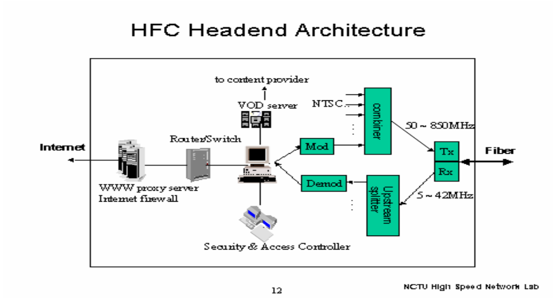
Frank Yeong-Sung Lin, Wei-Ming Yin, Ying-Dar Lin, and Chih-Hao Lin, IEICE Trans. Commun. Vol E85-B, No.10, October 2002

General Cable HFC Architecture



資料來源：中華電信北區分公司 國內多媒體網路現狀分析國內多媒體網路現狀分析
http://www.twaren.net/chinese/activity/news/TWAREN2004/achievement/4.pdf

Introduction



資料來源：NCTU high speed network lab

- 2-way HFC network
  - Downstream: point-to-multipoint, tree-and-branch network
  - Upstream: multipoint-to-point, bus network
    - TDMA slot based
    - Collision may occur
    - Each station should synchronize with the headend
- There are large propagation delay in HFC network thus each station should learn its distance from the headend.
  - The ranging process is needed to measure the distance between a station and the headend
  - Each ranging message is sent after a random delay (similar to pure Aloha)
  - Again, collision occurs when active stations transmit ranging packets simultaneously

Normal ranging process

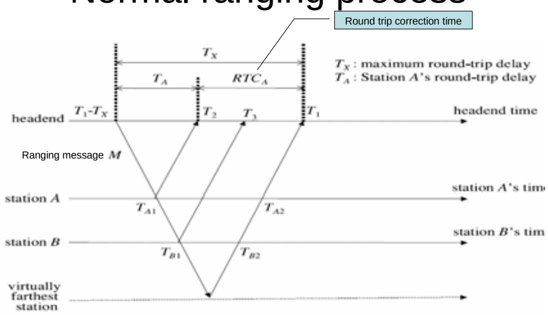


Fig. 1 Normal ranging process.

DOCIS ranging process

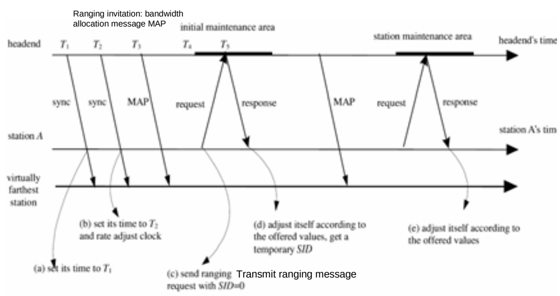


Fig. 2 The DOCSIS ranging process.

A contention cycle with blocked arrival

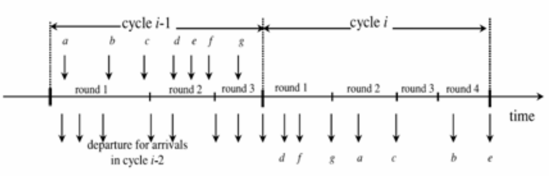


Fig. 3 A contention cycle with blocked arrivals.

• A Contention **cycle**, *completely* resolving *a group of unranged stations*, includes several contention rounds. Each **round** corresponds to the maintenance area in Fig.2.
• Each station must wait for a **random delay d** (0≦d ≦$|r_i|$) in every r_i round.
• **Block-access scheme**: Stations are activated in the current contention resolution cycle are prohibited from participating in this contention cycle

What is the optimal solution of a delay d?

- A long range delay
  - results in a long round time
  - increases the probability of successful message transmission
  - Increase the probability of a contention cycle containing a small number of rounds
- A short range delay
  - Reduces the round time
  - Increase the number of rounds in a contention cycle owing to frequent collisions
- The problem is to minimize the cycle time considering the range of random delay in each round
- Three random delay algorithms were proposed: Fixed Random Delay (FRD), Variable Random Delay (VRD), Optimal Random Delay (ORD)

FRD

- A fixed random delay d for each contention round is given
- p(i, j, d): j stations successfully transmit their packets among i active stations with delay d.
- <u>p(i, j, d) is calculated by exhaustive simulations</u>
- Average cycle time (ACT_{dn}) can be calculated by a finite state transition model

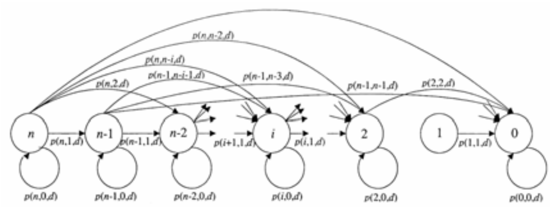


Fig. 4 State transition diagram for developing FRD.

$$
\begin{aligned}
ACT_{d_n} = {} & d * p(n,n,d) \\
& +2d * [p(n,n,d)p(n,0,d) \\
& + \sum_{i=1}^{n-2} p(n,i,d)p(n-i,n-i,d)] \\
& \cdots \\
& \cdots \\
& +Kd * \sum_{j} (\text{probability of a resolution} \\
& \quad \text{scenario } j \text{ with cycle time } Kd)
\end{aligned}
$$

K is determined when $(K+1)d < 10^{-5}$

VRD

- If there are k active stations in a contention round, the random delay is set to d_k

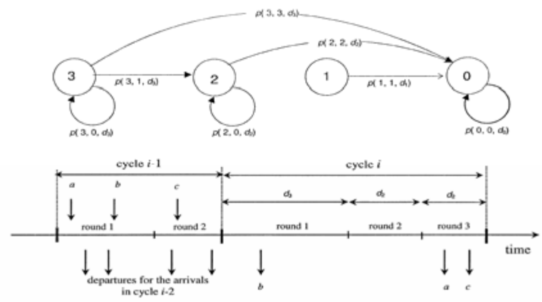


Fig. 5 State transition diagram for VRD.

The cycle time i is d3+d2+d2

ORD

- A globally optimal random delay for different numbers of active stations in each round thus minimizing the average cycle time
- $d_{i,opt}$ = globally optimal value d for each p(i, j, d)
- $d_{0,opt} = d_{1,opt} = 0$
- $d_{2,opt}$ = $ACT_{d_2} = \sum_{i=1}^{K} [i * d * p(2,0,d)^{i-1} p(2,2,d)]$ See page 14
- $d_{3,opt}$ = $ACT_{d_3} = \sum_{i=1}^{K} p(3,0,d)^{i-1} [i * d * p(3,3,d) + ACT_{d_{2,OPT}} * p(3,1,d)],$ See page 15

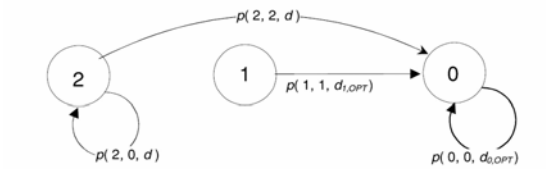


Fig. 6 State transition diagram for ORD to calculate $d_{2,OPT}$.

$$ACT_{d_2} = \sum_{i=1}^{K} [i * d * p(2,0,d)^{i-1} p(2,2,d)]$$

K is determined when (K+1)d < 10^{-5}

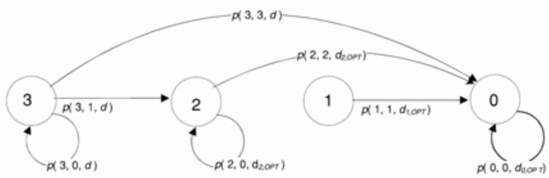


Fig. 7 State transition diagram for ORD to calculate $d_{3,OPT}$.

$$ACT_{d_3} = \sum_{i=1}^{K} p(3,0,d)^{i-1} [i * d * p(3,3,d) + ACT_{d_{2,OPT}} * p(3,1,d)],$$

Numerical Observation

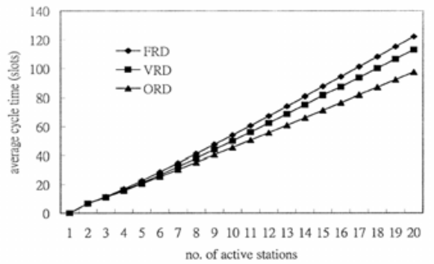


Fig. 8 Average cycle time for FRD, VRD, and ORD algorithms.

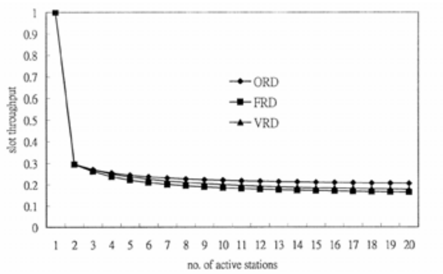


Fig. 9 Slot throughput for FRD, VRD, and ORD algorithms.

Slot throughput = (# of stations) / (average time of a ranging process)

Implementation Issues

- In previous simulation the number of un-ranged active stations in each contention round is assumed to be known
- However, in real world, only the number of collision clusters and the number of active stations that successfully transmitted the messages are known
- Sensitivity analysis
  - To determine the influence of the error in estimating the number of active stations on average cycle time

Sensitivity analysis of FRD

err = k, k=estimate(i)-i

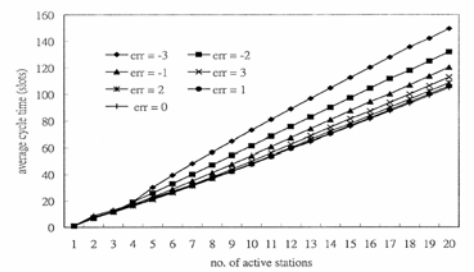


Fig. 10 Average cycle time of FRD with estimation errors.

Sensitivity analysis of ORD

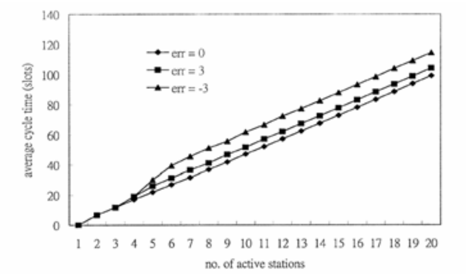


Fig. 11 Average cycle time of ORD with estimation errors.

- The result of the analysis indicates that the best strategy is to overestimate the number of active stations
- Two estimation schemes to enhance the throughput of the ranging process:
  - Maximum likelihood scheme
  - Average likelihood scheme

Maximum likelihood scheme

- Based on the probability model
- The most possible number of active stations in the next rounds is calculated
- p(i, j, k, d) = probability of j out of i active stations successfully transmitted with k collision clusters observed, given the random delay between 0 and d
- p(i, j, k, d)'s are calculated by exhaustive simulation
- The precise number of active stations is estimated so we needs historical information (the number of previous contention rounds, **window size**) to help to calculated the estimation

- Window size = 2
- 1st round:
  - If $j=j_0$, $k=k_0$, and $d=d_0$ are observed, then $i_{0,e}=\arg_i \max\{p(i, j_0, k_0, d_0)\}$
  - Estimate number of active stations in the second round = $\max\{i_{0,e}-j_0, 2k_0\}$
- 2nd round
  - If $j=j_1$, $k=k_1$, and $d=d_1$ are observed, then $i_{1,e}=\arg_i \max\{p(i+j_0, j_0, k_0, d_0) * p(i, j_1, k_1, d_1)\}$
  - Estimate number of active stations in the third round = $\max\{i_{1,e}-j_1, 2k_1\}$

Average likelihood scheme

- 1st round:
  - If $j=j_0$, $k=k_0$, and $d=d_0$ are observed, then

$$i_{0,e} = \left[\sum_i (i * p(i, j_0, k_0, d_0)) \right]$$

  - Estimate number of active stations in the second round = $\max\{i_{0,e}-j_0, 2k_0\}$
- 2nd round:
  - If $j=j_1$, $k=k_1$, and $d=d_1$ are observed, then

$$i_{1,e} = \left[\sum_i (i * p(i+j_0, j_0, k_0, d_0) * p(i, j_1, k_1, d_1)) \right]$$

  - Estimate number of active stations in the third round = $\max\{i_{1,e}-j_1, 2k_1\}$

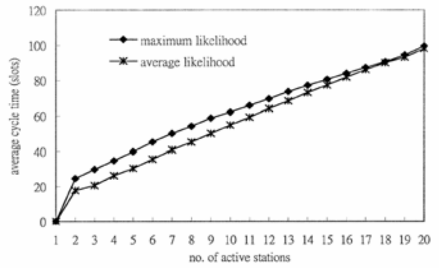


Fig. 12 Average cycle time for ORD with initial$(i) = i$.

Initial (i)= x: real number of active stations is i, estimation number is x

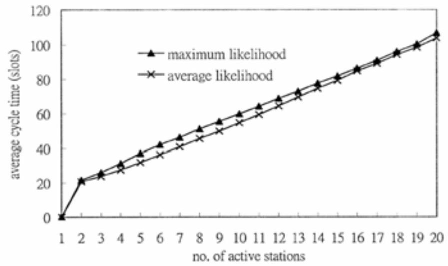


Fig. 13 Average cycle time for ORD with initial$(i) = 10$.

For N<=10, overestimation produces the same results as previously. However, underestimation does not significantly increased the average cycle time in either scheme. This is because the schemes are based on historical information not mere guess. So they can accommodate to the real situation.

Conclusion

- Three algorithms (FRD, VRD, ORD) were developed to determine the optimal random delay for each contention round so as to minimize the average cycle time, and these algorithms modeled the resolution process in a finite state machine with transition probabilities exhaustively calculated by simulation
- The ORD was demonstrated to effectively minimize the contention cycle time and approach optimal throughput from pure ALOHA
- According to the sensitivity analysis, it was preferably to overestimate the number of active stations than underestimate them
- The maximum likelihood and average likelihood schemes were effective even when the estimate of the number of initially active stations is inaccurate