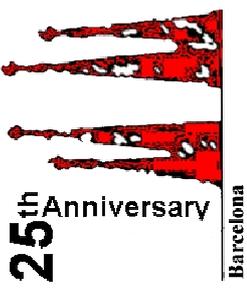




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INFOCOM 2006

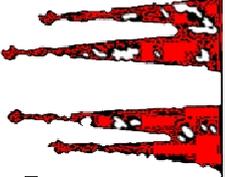


Analytical Modeling of Polling in PLC based AMR Systems

by

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Abstract

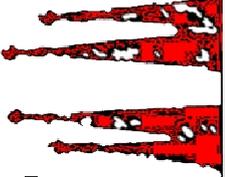
Polling is used routinely in many systems. Many of them, like AMR, need to poll devices through multihop structures formed by several repeaters.

The Poster presents a general analytical model of polling of these multihop systems.

It is based on a Markov Chain and provides explicit formulas for the probability of each state as well as for the recurrence time of the initial state from which the throughput of the system can be derived.

Curves showing the behavior of the system as a function of several parameters are provided.

Introduction (I)



AMR can be accomplished using different communication techniques such as Power Line Communication (PLC) or Wireless.

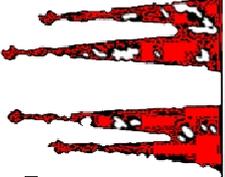
Communication systems which use the power cables themselves as communication medium are convenient for the Electrical Utilities.

Narrow band PLC is already a mature and low cost technology and has stable standards in Europe.

This type of communication due to the characteristics of power lines imply low throughput rates and high error rate levels that typically mean retry probabilities in the range from 1% to 20%.

The concentrator located at the Medium Voltage (MV) substation communicate with meters or customer devices through several intermediate relays.

Introduction (II)



The Poster concentrates on polling on multihop systems providing a Markov Chain model which is applicable to both narrowband as well as broadband PLC and most possibly to Wireless and emergency networks.

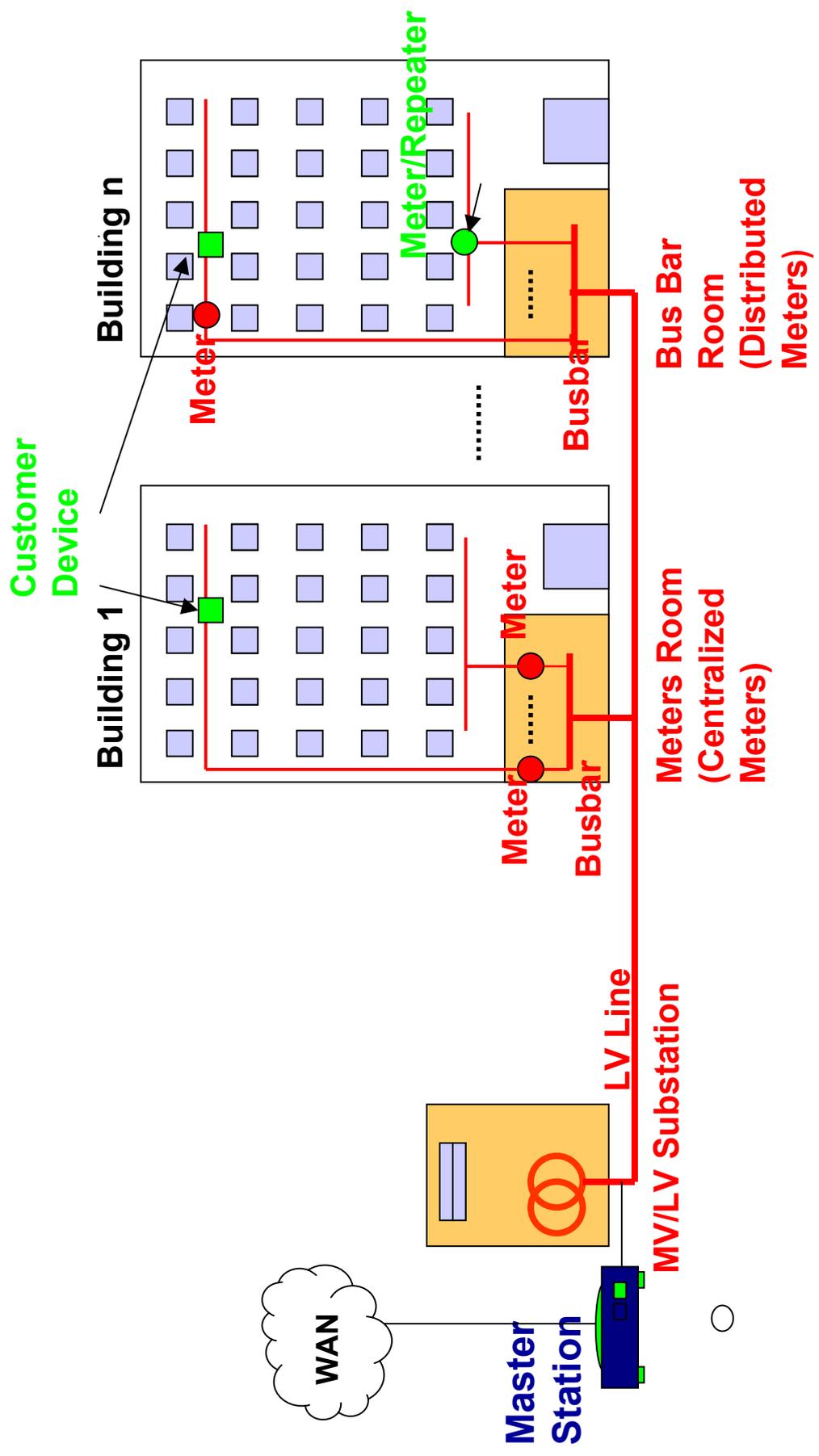
Despite of its widespread use, there are only a few analytical studies of polling in AMR and none to our best knowledge focuses on the multihop aspect.

The model includes two versions of procedure upon time-out expiration, one is the typical End-to-End Time-out and the other includes a Fix Delay to account for the reconfiguration of the multihop tree upon repeated failure of transmission.

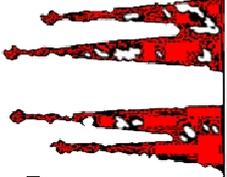
The model has been validated by the help of a simulation model based on OPNET Modeler.

AMR Layout

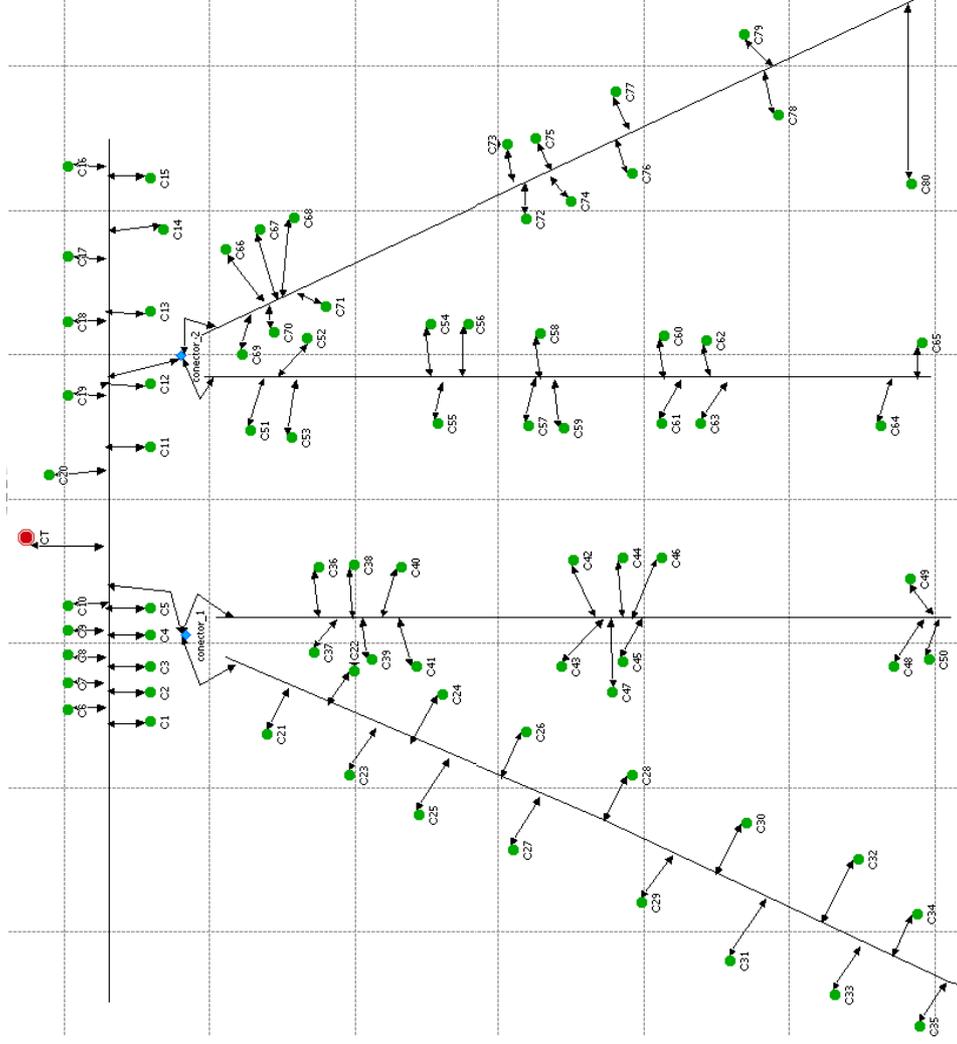
General Electrical Automatic Meter Reading (AMR) Layout



System's Architecture



- MASTER-SLAVE
- MULTIHOP (UP TO 8 LEVELS)
- SLAVES CAN ACT AS REPEATERS
- LARGE NUMBER OF SLAVES (>1000)
- HIGH LEVEL OF NOISE
- MASTER CONNECTED TO THE MV/LV TRANSFORMER



The Protocol

Typical polling protocol. Master polls the slaves through one or several repeaters.

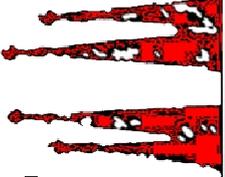
Two levels: hop level and global (End-to-End) level.

Automatic Repeat reQuest (ARQ) mechanism at the hop level.

- CRC
- Either, positive or implicit acknowledgments
- Not acknowledgments in case of error
- Maximum number of retries at the hop level

Global End-to-End Retransmission upon Global Time-Out expiration or upon reconfiguration of the multihop tree due to dialog failure.

The Model



Two dimensional discrete-time MARKOV CHAIN

States: (hop count level, number of effective retransmissions)

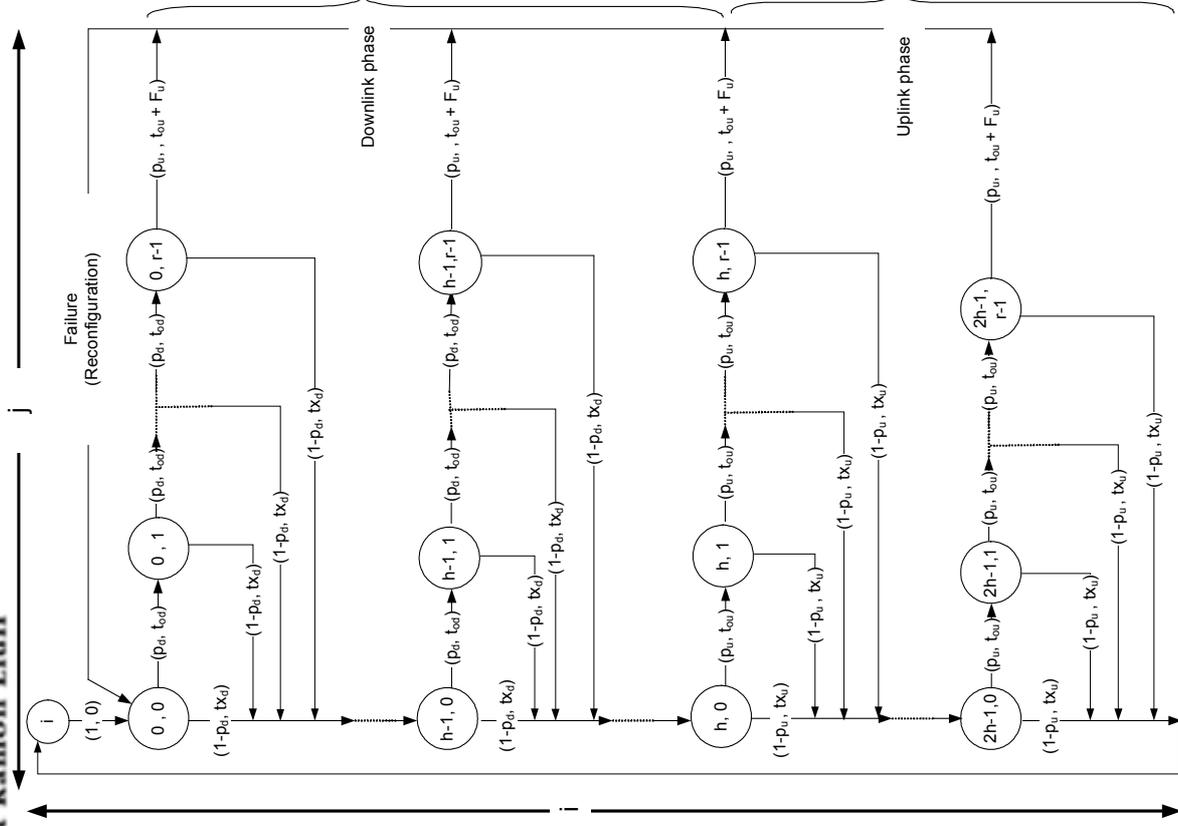
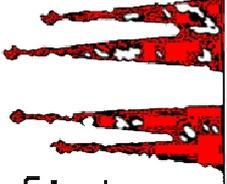
Irreducible Markov chain:

- All states are recurrent

- Any state is reachable from any other state.

The mean recurrence time of the initial state is the basic average delay of the system from which other performance measures like throughput can be derived.

Model 1: Tree Reconfiguration



Upon exhausting the hop retries the multihop tree is reconfigured.

This is modeled as a fixed delay F_i .

States:

(i, j) = (hop count level, number of effective retransmissions)

Parameters:

- Maximum number of hop retries (r) in downlink or uplink (rd, ru)
- Retransmission probability (pd, pu)
- Number of repeater levels (h)
- Transmission time (txd, txu)
- Retransmission time (tod, tou)
- Fix time to get the tree reconfigured (F)

State probability

Equilibrium equations of states (i,j):

$$p(i, j) = p \cdot p(i, j - 1) \quad \text{for } j \geq 1$$

where $p = p_d$ for $i \leq h - 1$ and $p = p_u$ for $i \geq h$

$$p(i, 0) = (1 - p) \cdot \sum_{0 \leq j \leq r-1} p(i-1, j)$$

where $p = p_d$ for $i \leq h$ and $p = p_u$ for $i \geq h + 1$

State probabilities:

$$p(i, j) = p(0, 0) \cdot (1 - p_d^{rd})^i \cdot p_d^j \quad \text{for: } i \leq h - 1$$

$$p(i, j) = p(0, 0) \cdot (1 - p_d^{rd})^h \cdot p_u^j \quad \text{for: } i = h$$

$$p(i, j) = p(0, 0) \cdot (1 - p_d^{rd})^h \cdot (1 - p_u^{ru})^{(i-h)} \cdot p_u^j \quad \text{for: } i \geq h + 1$$

Number of Visits

Probability of state (0,0):

$$p(0,0) = \frac{1}{\frac{1-p_d^{rd}}{1-p_d} + \frac{(1-p_d^{rd})^h \cdot (1-p_u^{ru})}{(1-p_u) \cdot p_u}} \cdot (1-(1-p_u^{ru})^h)$$

If downlink and uplink have the same parameters:

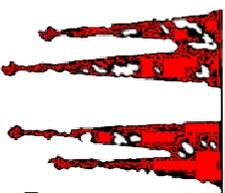
$$p(0,0) = \frac{(1-p) \cdot p^r}{(1-p^r) \cdot (1-(1-p^r)^{2h})}$$

Number of visits to states (i,0):

$$nv(i,0) = \frac{1}{(1-p_u^{ru})^{2h-i}} \quad \text{for: } i \geq h$$

$$nv(i,0) = \frac{1}{(1-p_u^{ru})^h \cdot (1-p_d^{rd})^{h-i}} \quad \text{for: } i \leq h-1$$

Model 1: Delay



$$D = \sum_{0 \leq i \leq 2h-1} nv(i,0) * d(i,0)$$

Where:

- nv(i,0)=average number of visits to state (i,0)
- d(i,0)=delay associated exclusively to state (i,0)

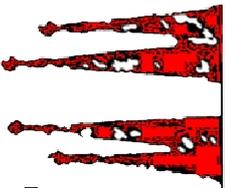
Delay associated exclusively to state (i,0):

$$d_k(i,0) = p_k^{r_k} \cdot (t_{0k} \cdot (r_k - 1) + F_k) + \sum_{0 \leq j \leq r_k - 1} p_k^j \cdot (1 - p_k) \cdot (t_{0k} \cdot j + t_{xk})$$

$$d_k(i,0) = p_k^{r_k} \cdot (t_{0k} \cdot (r_k - 1) + F_k) + (1 - p_k^{r_k}) \cdot t_{xk} + t_{0k} \cdot p_k \cdot \left[\frac{1 - p_k^{r_k - 1}}{1 - p_k} - (r_k - 1) \cdot p_k^{r_k - 1} \right]$$

(k equal to d for downlink and to u for uplink)

Model 1: Delay (II)



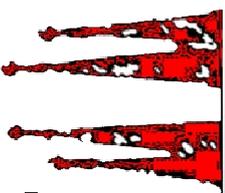
$$D = d_d \cdot \frac{1}{p_d^r \cdot (1 - p_u^r)^h} \cdot \left(\frac{1}{(1 - p_d^r)^h} - 1 \right) + d_u \cdot \frac{1}{p_u^r} \cdot \left(\frac{1}{(1 - p_u^r)^h} - 1 \right)$$

In the case when downlink and uplink parameters coincide:

$$D = \frac{d}{p^r} \cdot \left(\frac{1 - (1 - p^r)^{2h}}{(1 - p^r)^{2h}} \right)$$

Throughput = payload / D

Model 2



Delay associated exclusively to state $(i,0)$:

$$d'_k(i,0) = (1 - p_k^{r_i}) \cdot t_{xk} + t_{0k} \cdot p_k \cdot \left[\frac{1 - p_k^{r_k - 1}}{1 - p} - (r_k - 1) \cdot p_k^{r_k - 1} \right]$$

Average System Delay:

$$D' = \sum_{0 \leq i \leq 2h-1} d'(i,0) + T_0 \cdot \sum_{1 \leq i \leq 2h-1} nv(i,0) * p_i^{r_i}$$

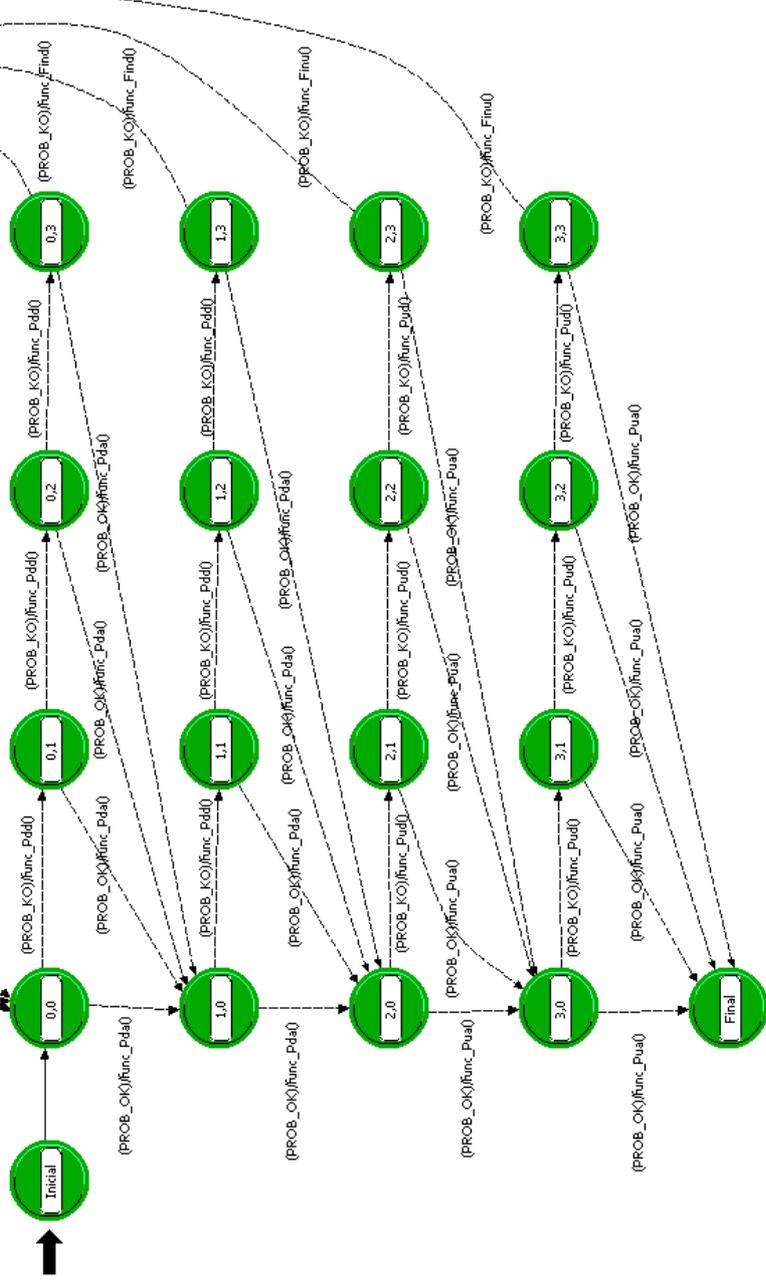
$$D' = h \cdot (d'_d + d'_u) + T_0 \cdot \left(\frac{1}{(1 - p_u^{r_u})^h \cdot (1 - p_d^{r_d})^{h-1}} - 1 \right)$$

Necessary time-out value to avoid collisions:

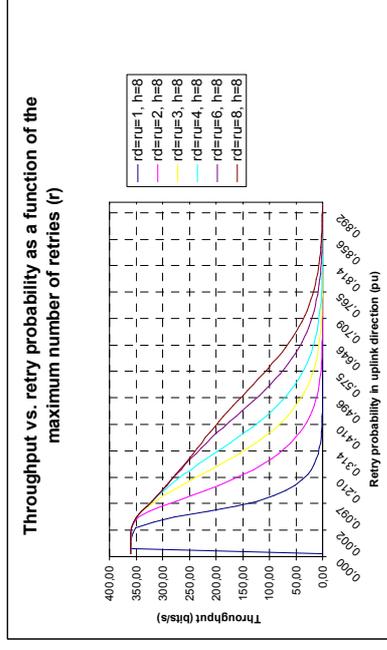
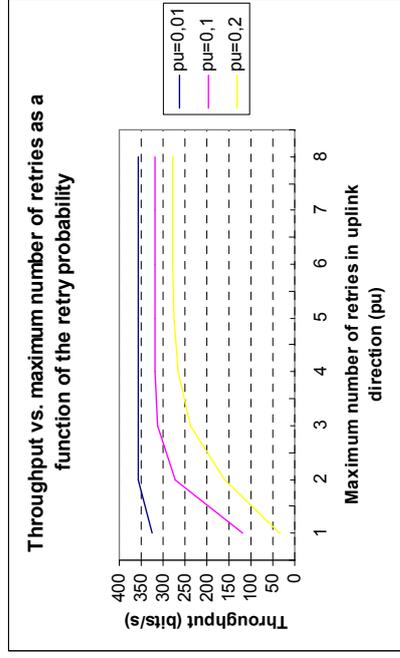
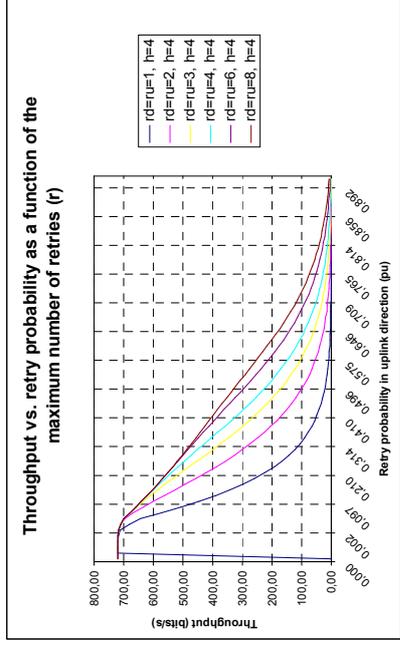
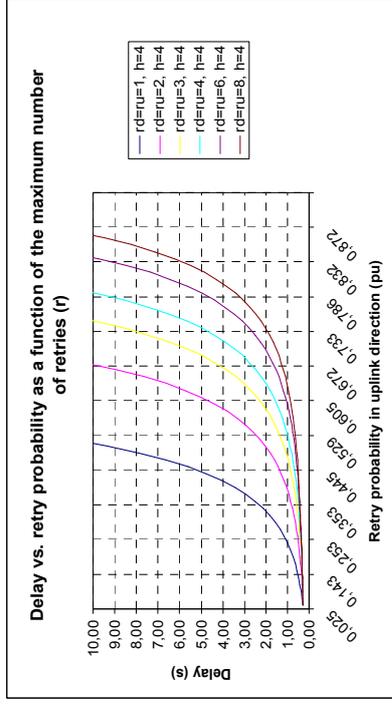
$$T_{0\max} = T_{0\min} + h \cdot (t_{od} \cdot (r_d - 1) + t_{ou} \cdot (r_u - 1)) \quad T_{0\min} = h \cdot (t_{xd} + t_{xu})$$

Validation by Simulation

- Monte Carlo simulation using OPNET Modeler
- Up to 10.000 simulations using several scenarios
- Deviation of 1 %



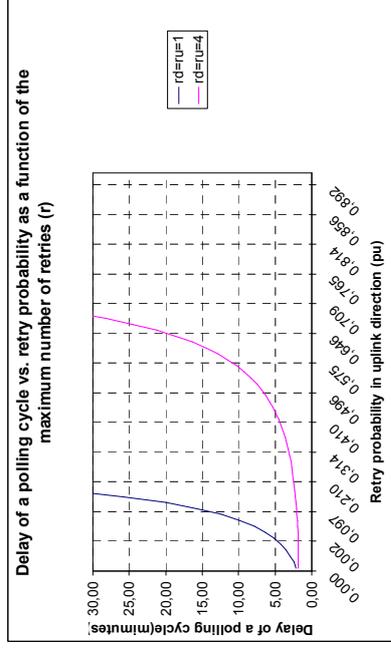
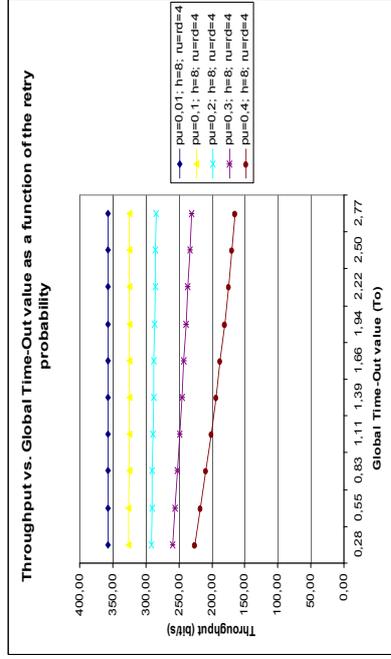
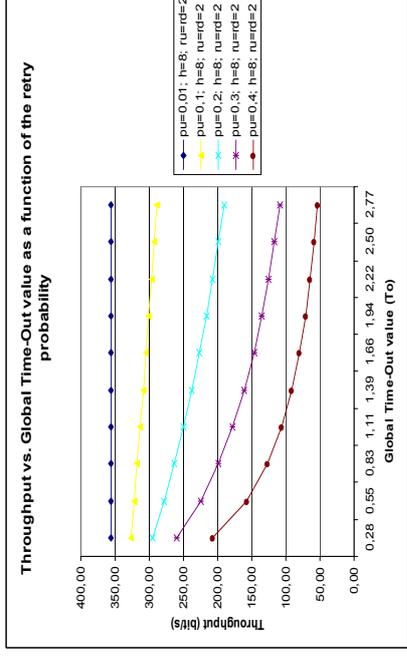
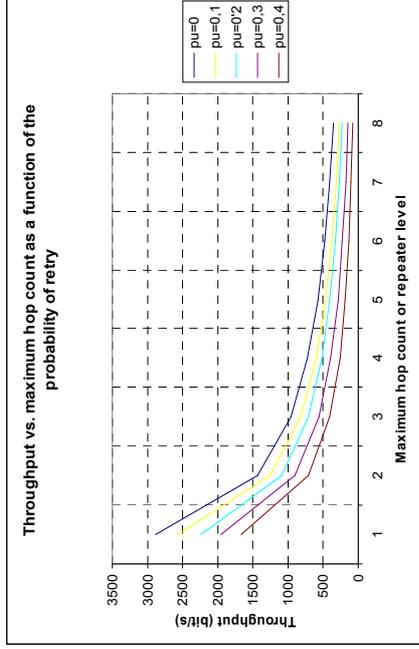
Results for Model 1 (I)



- Throughput is almost inversely proportional to the number of hops.
- The higher the probability of error the higher the need for retries

-Typically a maximum number of retries equal or higher than 4 is necessary to achieve maximum system throughput

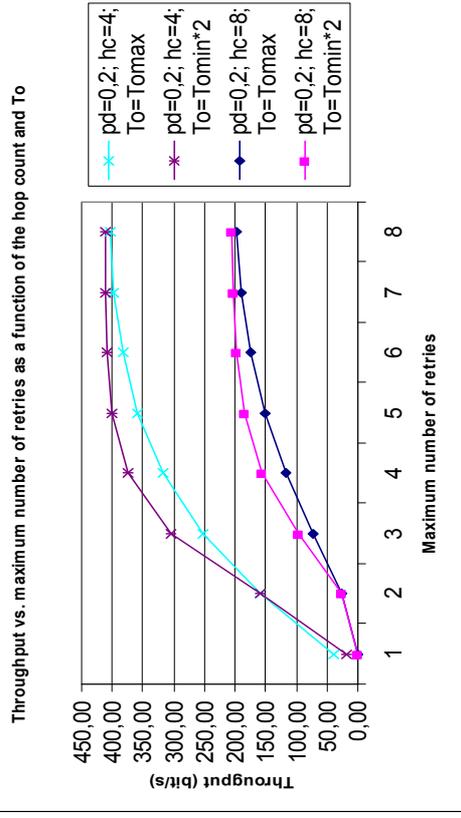
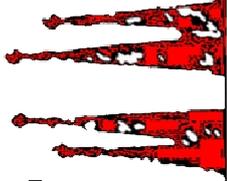
Results for Model 1 (II)



- Hop count is the most important parameter to take into account to create the tree.
- The higher the probability of error the higher the sensibility to To (Or F in Model 1)

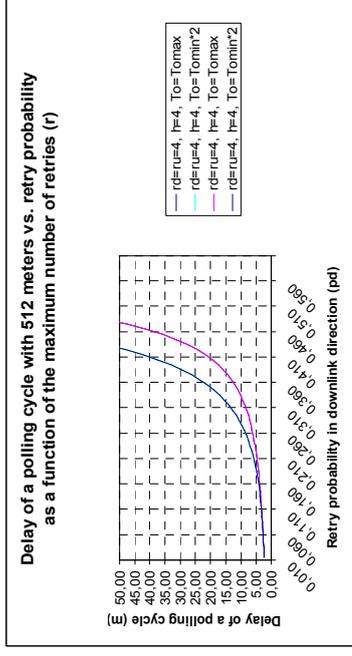
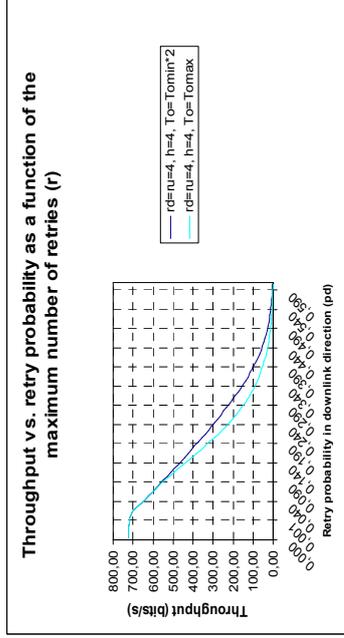
- Increasing the number of retries reduces this sensibility to To (Or F in Model 1).
- To keep the polling cycle for 512 meters reasonable (under 5 minutes) it is necessary to use at least a maximum number of retries of 4.

Time Out Reduction Effect

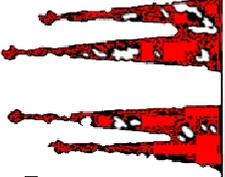


Reducing the Time-Out value is a way of improving throughput at the expense of a probability of collision.

The effect of reducing To is important for the range of retries of interest (around 4).



Reducing To allows for reducing the number of retries while maintaining the throughput. It also reduces significantly the polling cycle for very high error rates.



Conclusions

SIMPLE MODEL OF POLLING IN MULTIHOP SYSTEMS

EXPLICIT FORMULAS FOR THE STATE PROBABILITIES, DELAY AND THROUGHPUT OF THE SYSTEM

USEFUL FOR AMR AS WELL AS FOR SIMILAR ENVIRONMENTS (AD-HOC AND SENSOR NETWORKS, EMERGENCY NETWORKS...)

CALCULATION OF THE EFFECT OF DIFFERENT PARAMETERS ON SYSTEM DELAY AND THROUGHPUT:

FUTURE:

- **REFINE THE MODEL TO INCLUDE :**
 - **ERROR PACKET TO THE MASTER**
 - **MARKOV MODULATED NOISE**
- **ANALYZE OTHER IMPROVEMENTS SUCH AS THE POSSIBILITY OF SCHEDULING SIMULTANEOUS POLLS**