Modelling of need for multiple relays for ensuring seamless mobility.

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Abstract – **seamless mobility is a requirement for MAUC and quite lots of work is already involved [6-18]. To achieve seamlessness of mobility in a multi-relay MAUC topography, quite a lot of back-end work must be carried out for proactively enabling potential "next-relays" and cause resource reservations. It is important to know trends of CBRs which will need exactly 1 relay, 2 relays, 3 relays….in the environment for policy formulations and improvement in resource management. This has been carried out in a previous paper [5] where trends for need of exact relay numbers have been detailed. However, it may be more useful to consider the trends for number of CBRs requiring more than 1 relay, more/less than 2 relays, more/less than 3 relays,….for more appropriate formulation of policies. From a designer/programmer's point of view, it may be easier to consider rightly that a CBR may need for example more than 5 relays or less than 8 relays rather than exactly 6 relays.**

This paper is therefore a direct follow-up of a previous paper [5]. The objective of this paper is to present the reworked results of combined data from 17 sets of experiments to model the need for greater/less than specific numbers of relays, in the form of graphs and deriving appropriate conclusions.

Key terms: MAUC-Mobile and Ubiquitous Computing, CBR-Constant Bit Rate.

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1. Introduction

1.1 Brief of this work.

Basically, this section follows from the introduction identified in the previous paper [5] with small extensions as detailed below:

Part (iii) in section 1.2 can be extended as: "A way of estimating probability of a CBR needing only 1 relay, only 2 relays, ……and greater than 1 relay, greater/less than 2 relays, greater/less than 3 relays…..until the maximum number of relays used."

Part (i) in number 2 under section 1.3 can be extended as: "From probabilities of CBR needing only 1 relay, 2 relays,… and greater than 1 (>1) relays, >2 or less than 2 (<2) relays, >3 or <3 relays, metrics about degree of mobility can be formulated.

1.2 Rationale of this work.

Pervasive Computing is still a developing paradigm where necessary reliable components are still subject to research and development [19]. Even if empirical/theoretical predictability models based on simulations are put forward at present times, it will take seriously long time to achieve sufficient components to make predictability of very exact resource consumptions and mobility metrics feasible. Starting from present era of developments in Ubicomp, designers/programmers will be more interested in having predictability ranges which can be applied over wide or narrow ranges, e.g. proportion of CBRs requiring more than 2 relays or between 6 and 8 (inclusive) relays. Preparing communication policies based on quite wide ranges will increase probability of success of such policies. This can also be applied gradually, i.e. as components and support for ubicomp increases and become more refined, communication policies over narrower ranges can be better envisaged.

Hence data that was prepared for previous paper is being reworked to suit the above characteristics in view to provide support for more constructive approach for ubicomp predictability models.

The key contribution of this paper is the development of an empirical, simulation-based model of the % of transmissions requiring more than and less than a specified number of relays in various multi-relay scenarios, taking into consideration exact location-aware transmission strategies. The model suggested in this paper is the exponential model of the form

$$F(x) = c*\exp(-d*(x-2)) + f$$

The rest of this paper is organised as follows: section 2-experiment design, section 3-Results and observations, section 4- Conclusion and References.

2. Experiment Design

Again, this follows from previous paper [5] with a few additions. The following can be introduced between part (i) and part (ii) as follows:

"From part (i) above, number of CBRs needing more than 1 (>1) relays, >2 relays, >3 relays…. can be gathered. Corresponding fractions and percentages can be computed. Data for less than 2 (<2) relays, <3 relays, <4 relays can also be derived"

3. Results and observations.

Same tabular results as in section 3.1 in previous paper [5] is used here, to compute the following where *V(n>x)* must be read as %CBR needing more than *x* relays.

3.1 Trend Analysis of % CBRs needing greater than x relays V(n>x).

1. For *x*=1.

Relays	2	3	4	5	6
V(n>1)	75.08	78.89	81.59	83.48	84.51

Relays	7	8	9	10	11
V(n>1)	84.83	85.46	85.94	85.71	86.43

Relays	12	13	14	15	16
V(n>1)	86.59	87.54	87.70	87.78	87.94

Relays	25
V(n>1)	88.49

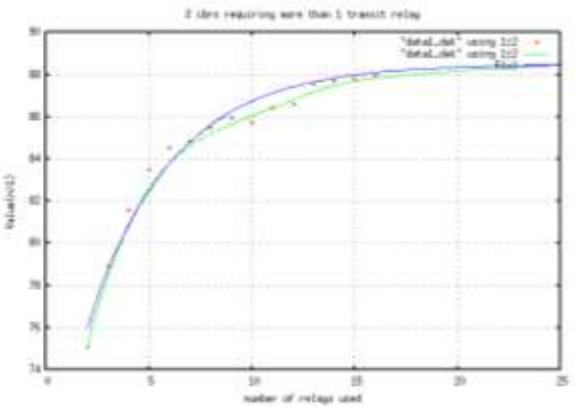

Fig 1: Trend Analysis of V(n>1).

The curve obtained through smooth Bezier is very convincing as an inverse exponential distribution. The equation obtained is

$$F(x)=-12.5031 * \exp(-0.244952*(x-2)) + 88.5$$

(x-2) is again found useful since this study starts from 2 relays in the topography. This graph shows an interesting observation: even for as few as 2 relays in a topography of 300x300 m^2, the proportion of CBRs needing more than 1 relay is as high as 75.08%. It indicates that quite significant amount of provisions may be reserved. The implications may be high for large number of nodes.

As the number of relays increases, the value of V(n>1) increases at a decresing rate until for 13 relays where it reaches value 87.54%. Beyond this number of relays, the value of V(n>1) can be used to grade the type of proactive provisioning that may be needed, i.e. the amount of resources to be reserved, time range within which these operations must be completed, refreshal or update frequencies needed and possible implications be catered, for example, if the update frequency is not high enough for large number of relays, then maybe proactively enabling next-hop neighbours may also be desirable.

Another argument can be that the range of variation of the values of V(n>1) is between 75.08 and 88.5. the range is less than 13.5. This range may be considered very small so that a single consistent method of proactive enabling of neighbour-relays may be devised and applied, i.e., no need for adaptation of the policy with respect to number of relays (relay density) being used.

Logically enough, the trend G(x) for number of CBRs needing less than or equal to 1 relay (V(n≤1)) or put differently CBRs needing less than 2 relays (V(n<2)) can be obtained by taking 100-F(x)

$$G(X)=100-F(X)$$
$$=100-[-12.5031 * \exp(-0.244952*(x-2)) + 88.5]$$
$$= 12.5031 * \exp(-0.244952*(x-2)) + 11.5$$

Quite obviously this is extremely close to equation obtained in part 1 of section 3.3 in previous paper [5].

2. For *x*=2.

Relays	3	4	5	6	7
V(n>2)	59.38	68.49	71.45	74.37	74.29

Relays	8	9	10	11	12
V(n>2)	75.71	77.07	77.61	78.33	78.73

Relays	13	14	15	16	25
V(n>2)	79.52	80.08	80.56	80.56	81.98

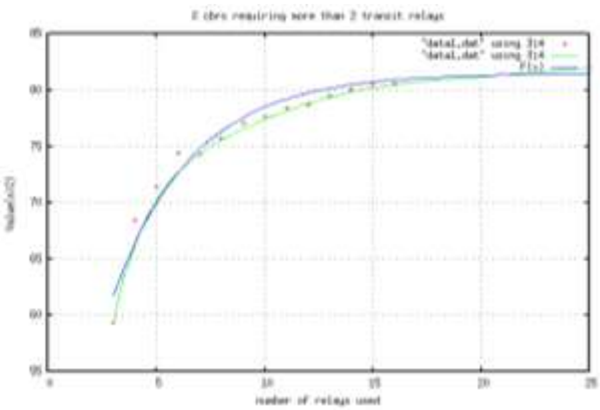

Fig 2: Trend Analysis of V(n>2).

Here also, the curve obtained through smooth Bezier is very convincing as inverse exponential distribution. The equation obtained is

F(x)=-25.885 * exp (-0.26965*(x-2)) + 81.5

For as few as 3 relays in the topography, V(n>2) is as high as 59.38%. it indicates, again, that the need for proactive provisioning of neighbouring relays starts at an already high value. As the number of relays increases, the value of V(n>2) increases at a decreasing rate until for 16 relays where it starts stabilising at around 81.5%.

Here for V(n≤2) or V(n<3), the trend G(x) will be

G(X)=100-F(X)
=100-[-25.885 * exp (-0.26965*(x-2)) + 81.5]
= 25.885 * exp (-0.26965*(x-2)) + 18.5

3. For *x*=3.

Relays	4	5	6	7	8
V(n>3)	50.03	56.51	63.59	65.24	68.41

Relays	9	10	11	12	13
V(n>3)	70.48	71.50	72.82	73.81	74.44

Relays	14	15	16	25
V(n>3)	75.40	75.40	76.03	78.17

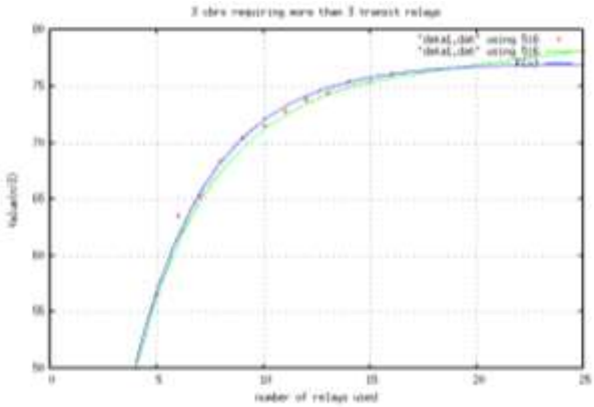

Fig 3: Trend Analysis of V(n>3).

Again, the curve obtained through smooth Bezier is convincing as inverse exponential distribution with equation

F(x)=-46.2096 * exp (-0.27666*(x-2)) + 77.06

Again, the distribution starts at a high enough value of 50.03. The need for proactive enabling starts at a moderately high value but increases with increasing relay density.

Here for V(n≤3) or V(n<4), the trend G(x) will be

G(X)=100-F(X)
=100-[-46.2096 * exp (-0.27666*(x-2)) + 77.06]
= 46.2096 * exp (-0.27666*(x-2)) + 22.94

4. For *x*=4.

Relays	5	6	7	8	9
V(n>4)	31.27	45.96	49.29	58.33	61.83

Relays	10	11	12	13	14
V(n>4)	62.69	65.87	67.06	68.49	70.32

Relays	15	16	25
V(n>4)	70.87	71.27	74.52

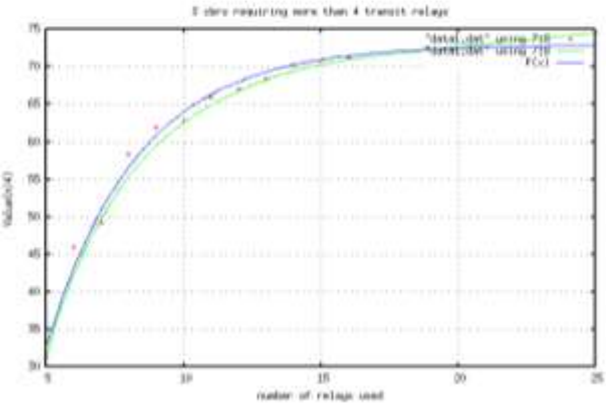

Fig 4: Trend Analysis of V(n>4).

The curve obtained through smooth Bezier is convincing as inverse exponential distribution with equation.

F(x)=-98.979 * exp (-0.300683*(x-2)) + 72.9479

The distribution starts at a moderate value of 31.27. A specific communication policy with projected number of transit relays to be used at greater than 4 may not give significant success at relay densities just above 4 (5,6 and 7). Designers/programmers of communication policies must make deeper research to assert if these success rates below 50% are meaningful enough. But for sure, as from relay densities above 7, such a policy will bring significant return, and hence will be beneficial.

Here for V(n≤4) or V(n<5), the trend G(x) will be

G(X)=100-[-98.979*exp(-0.300683*(x-2))+ 72.9479]
= 98.979*exp(-0.300683*(x-2))+ 27.0521

5. For *x*=5.

Relays	6	7	8	9	10
V(n>5)	23.10	32.62	42.46	50.32	51.26

Relays	11	12	13	14	15
V(n>5)	56.79	59.21	59.94	62.54	64.29

Relays	16	25
V(n>5)	65.08	70.87

Again, inverse exponential distribution is fitting with equation

F(x)=-123.829 * exp (-0.246482*(x-2)) + 69.6949

Here also, the distribution starts at a moderately low value and start giving high (>50%) success rates as from 9 relays onwards. It depicts that a corresponding communication policy will be successful with relay density of 9 and above in the topography.

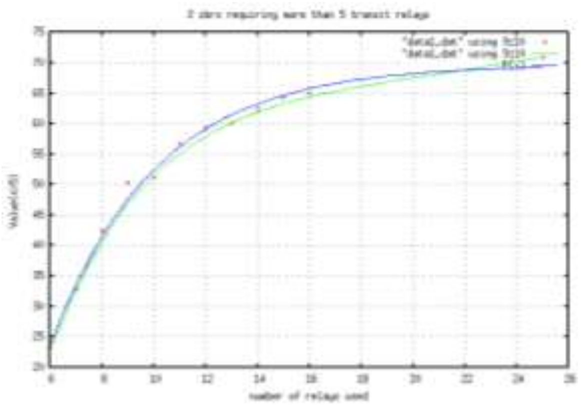

Fig 5: Trend Analysis of V(n>5).

Here for V(n≤5) or V(n<6), the trend G(x) will be

G(X)=100-[-123.829*exp(-0.246482*(x-2))+69.6949]
= 123.829*exp(-0.246482*(x-2))+ 30.3051

6. For *x*=6.

Relays	7	8	9	10	11
V(n>6)	12.56	25.87	33.41	36.97	44.21

Relays	12	13	14	15	16
V(n>6)	48.41	49.76	53.83	56.92	58.17

Relays	25
V(n>6)	66.90

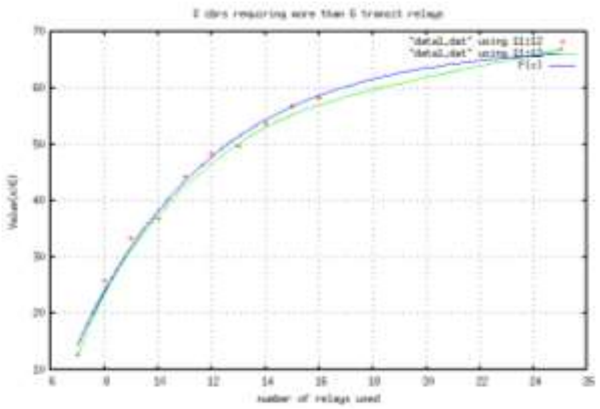

Fig 6: Trend Analysis of V(n>6).

Again, inverse exponential distribution with equation

F(x)=-143.329 * exp (-0.198018*(x-2)) + 67.6391

The distribution starts at a low value and start giving high success rates as from 13 relays onwards. A tailor-made communication policy for a node requiring more than 6 relays will be of high return as from 13 relays and above over a topography of 300x300 m^2.

Here for V(n≤6) or V(n<7), the trend G(x) will be

G(X)=100-[-143.329*exp(-0.198018*(x-2))+67.6391]
= 143.329*exp(-0.198018*(x-2)) + 32.36091

7. For *x*=7.

Relays	8	9	10	11	12
V(n>7)	10.08	17.71	23.57	31.59	36.03

Relays	13	14	15	16	25
V(n>7)	38.73	42.70	46.51	48.27	62.70

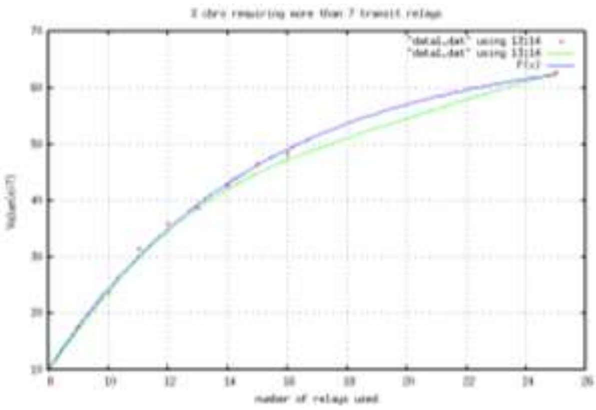

Fig 7: Trend Analysis of V(n>7).

Again, inverse exponential distribution is fitting with equation

F(x)=-134.346 * exp (-0.142117*(x-2)) + 67.4969

The distribution starts at a low value and start giving considerable success rates as from 13 relays and high success rates as from above 16 relays.

Here for V(n≤7) or V(n<8), the trend G(x) will be

G(X)=100-[-134.346*exp(-0.142117*(x-2))+67.4969]
= 134.346 * exp (-0.142117*(x-2)) + 32.5031

8. For *x*=8.

Relays	9	10	11	12	13
V(n>8)	6.27	10.63	18.02	22.70	26.43

Relays	14	15	16	25
V(n>8)	31.35	35.63	37.54	56.22

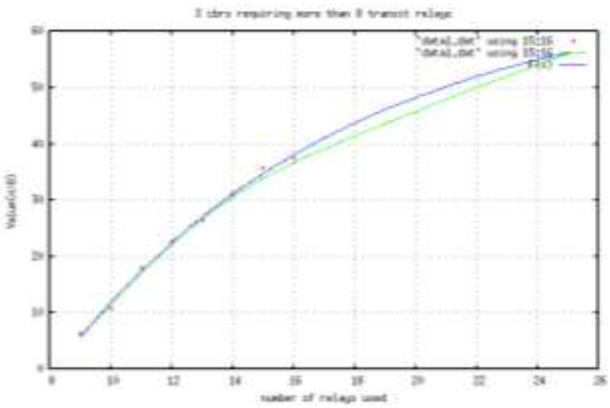

Fig 8: Trend Analysis of V(n>8).

Again, inverse exponential distribution is fitting with equation

F(x)=-130.082 * exp (-0.105882*(x-2)) + 67.6331

The curvature of the curve is tending to flatten. Here also, the distribution starts at a low value and start giving considerable success rates as from 16 relays and high values at around 23 relays.

Here for V(n≤8) or V(n<9), the trend G(x) will be
G(X)=100-[-130.082*exp(-0.105882*(x-2))+67.6331]
= 130.082*exp(-0.105882*(x-2)) + 32.3669

9. For *x*=9.

Relays	10	11	12	13	14
V(n>9)	4.05	9.14	13.02	16.94	20.63

Relays	15	16	25
V(n>9)	24.68	27.54	48.59

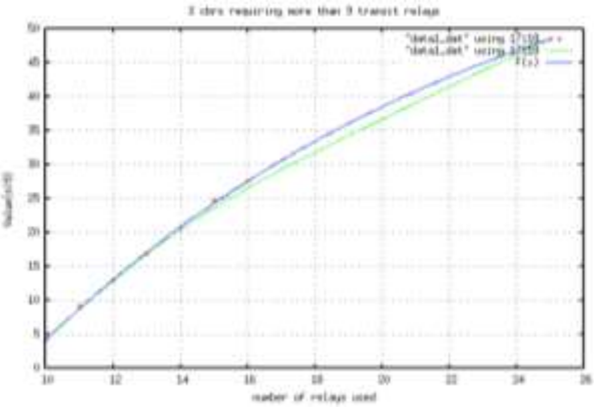

Fig 9: Trend Analysis of V(n>9).

Again, inverse exponential distribution is fitting with equation
F(x)=-119.606 * exp (-0.0697839*(x-2)) + 72.6237

The curvature of the fit is flattening further. The distribution starts with a very low value and start giving considerable success rates as from above 16 relays. The success rate, even at highest relay density experimented, does not exceed 50%.

Here for V(n≤9) or V(n<10), the trend G(x) will be
G(X)=100-[-119.606*exp(-0.0697839*(x-2))+72.6237]
= 119.606*exp(-0.0697839*(x-2)) + 27.3763

10. For *x*=10

Relays	11	12	13	14	15
V(n>10)	2.94	5.89	7.87	12.03	15.56

Relays	16	25
V(n>10)	17.78	41.32

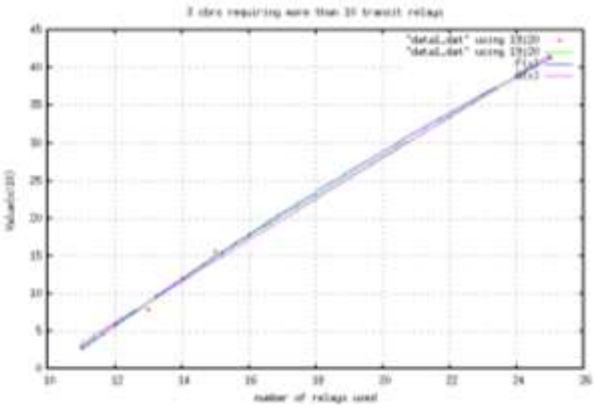

Fig 10: Trend Analysis of V(n>10).

This plot is different from previous plots. The plot has been tested with 2 hypothetic equations in gnuplot. The inverse exponential and linear (y=d*x* + f) models. Both are mathematically acceptable as they are giving reduced chi-square value less than 1. However, the exponential model is preferred since its chi-square value is smaller (0.400075 against 0.710852 for the linear model). Equations of curve could be
F(x)=-176.222 * exp (-0.0223733*(x-2)) – 146.684

Or F(x)=2.74353(x) – 26.7748

The distribution starts with a very low value and start giving considerable success rates from above 16 relays. Again, even at highest relay density the success rate is less than 50%.

A specific communication policy for above ten transit relays may not have so much need in a relay density of less than 26 over topography of 300x300m2. It could be useful at higher relay densities but such high relay densities will probably not be implemented due to its high costs. Development of such a communication policy will hence not be advisable.

Here for V(n≤10) or V(n<11), the trend G(x) will be
G(X)=100-[-176.222 * exp (-0.0223733*(x-2)) – 146.684]
= 176.222 * exp (-0.0223733*(x-2))- 46.684

11. For *x*=11

Relays	12	13	14	15	16
V(n>11)	1.67	2.54	5.48	9.17	11.21

Relays	25
V(n>11)	31.67

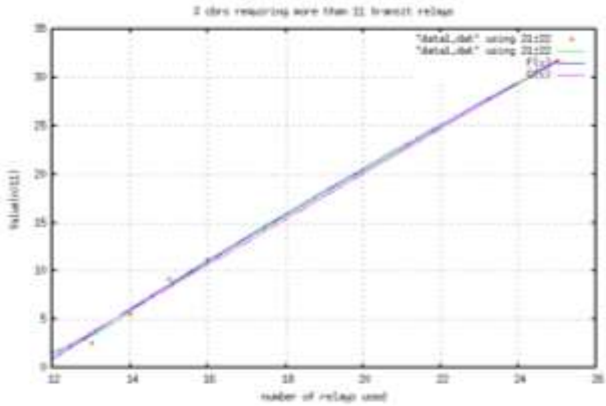

Fig 11: Trend Analysis of V(n>11).

This plot also has been tested with exponential and linear models. Again both models are acceptable since the reduced chi-square values are less than 1. The exponential model still holds with a chi-square value of 0.741052 compared to 0.650151 for the linear model. The equations of the fitting models are:
F(x)=-195.485 * exp (-0.0156738*(x-2)) – 168.016

Or F(x)=2.35389(x) – 26.98

The distribution starts with a very low value and gives a fair success rate at 25 relays. A corresponding communication policy will NOT be of good return.

Here for $V(n \leq 11)$ or $V(n<12)$, the trend G(x) will be
G(X)=100-[-195.485 * exp (-0.0156738*(x-2)) + 168.016]
= 195.485 * exp (-0.0156738*(x-2))+ 68.016

12. For *x*=12

Relays	13	14	15	16	25
V(n>12)	0.79	1.90	3.89	6.54	25.40

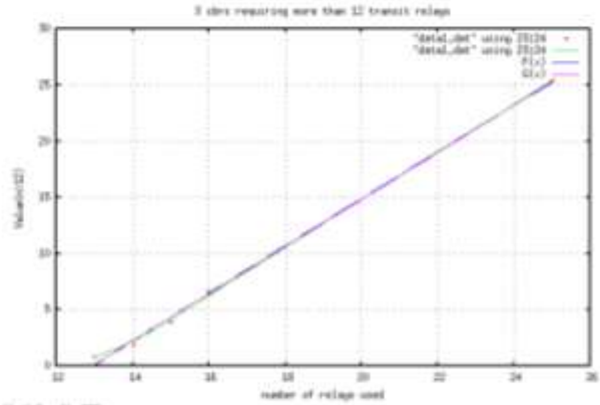

Fig 12: Trend Analysis of V(n>12).

The results resemble previous plot. The exponential and linear models are both successful. The exponential model still holds with a chi-square value of 0.41371 compared to 0.251068 for the linear model. The equations of the fitting models are:

F(x)=-730.87 * exp (-0.0030214*(x-2)) + 707.074

Or F(x)=2.09687(x) – 27.104

The distribution starts with an extremely low value and gives a poor to moderate success rate at 25 relays. A corresponding communication policy will NOT be of good return.

Here for $V(n \leq 12)$ or $V(n<13)$, the trend G(x) will be
G(X)=100-[-730.87 * exp (-0.0030214*(x-2)) + 707.074]
= 730.87 * exp (-0.0030214*(x-2)) + 607.074

NOTE: Again, it will not be appropriate to study for values of *x* greater than 12, since there will be fewer sets of data, thus reducing the reliability of graphical plots.

These sets of observations will serve towards producing policies of how much resource reservations could be carried out at each neighbour relay when transmission is projected to have more/less than a specific number of relays.

3.2 Observations from these Results.

1. All experiments examined have followed the inverse exponential model of the form
   F(x) = a * exp (-b*(x-2)) + c
   It is also observed that magnitude of b mostly decreases over successive experiments and hence curves tend to flatten.
2. For *x* taking values 11 and 12, mostly the exponential model remains applicable but can be approximated by linear models since degree of curvature on plot is very low. This is supported by the fact that b takes very small values (<0.02).
3. Specific tailor-made communication policies are empirically successful for values of *x* ranging from 2 to 8. For values of *x* between 9 and 10, such policies will bring poor to moderate success rates. For values of *x* above 10, they will not be worth the investments.
4. It will be improbable to have more than 25 relays in topography of $300x300m^2$.
5. It is hence recommended to have as support of efficient Ubicomp, communication policies for values of x ranging from 2 till 8. This could be extended to 9 and 10 only if the process is of low effort and cost as they are expected to bring low return.
6. It is not recommended to have communication policies for values of *x* above 10 in a topography of 300x300 m^2 or larger.

3.3 Using Results for modelling %CBR needing bounded number of Relays.

If a designer wishes to have a model for bounded number of relays, e.g. %CBR needing greater than 2 but less than 6 relays, he can combine results from above as follows:

$Y(X) = F(X)_{\text{at } x=2} - F(X)_{\text{at } x=5}$
= -25.885* exp (-0.26965*(x-2)) + 81.5 –[-123.885* exp (-0.246482*(x-2)) + 69.6949]
=123.885* exp (-0.246482*(x-2)) -25.885* exp (-0.26965*(x-2)) + 11.8051

The above illustration can be adapted for any bounded ranges between 1 and 12 relays. It is noted that only the constant term will be subject to a subtraction operation. The exponential terms will appear in the resulting model equation.

4. Conclusion.

This piece of study is a follow-up of 5 previous paper [1-5]. The nature of this piece of study has been to study several sets of re-compiled data from previous paper [5], formulate graphs and equations of curves, hence the presence of many graphs in this paper.

This piece of study has extended the study for multiple transit relays for transmission and produce additional support models which can help in formulation of policies of resource reservations and development of ubicomp support components. The model which has very convincingly been applicable is an inverse exponential model of the form

$$F(x) = a * \exp(-b*(x-2)) + c$$

This model will assist in prediction in a MAUC environment and preparing groundwork for more advanced experiments. It can also serve in formulating base models to build appropriate communication policies against a known projected model of success rates or as a reference against which some reliability features of MAUC can be rated. It can ultimately help in formulation of appropriate metrics and new architecture support in a MAUC environment.

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