Model of Energy Savings achievable with Location-aware Transmission in UbiComp Using Relays.

M. Kaleem GALAMALI, Assoc. Prof Nawaz MOHAMUDALLY

Abstract **– The field of Ubiquitous computing has opened several new directions of research. Much achievements have been reached [1-16]. Much research has been done concerning energy management in the field of Ubicomp. No doubt that effective use of relays can help reduce amount of energy required for transmission since energy required varies to the square of distance. Presence of relays in an environment can also help a lot in location tracking of nodes present in a topography. What is missing in this field is a way to model and predict amount/proportion of energy saved and metrics concerned, from a software engineering perspective, when applying relays in a ubicomp topography.**

This paper is a follow-up of 2 previous papers titled "Model of Energy Savings achieved with Location-Aware Node-to-Node transmission in Ubicomp" and "Model of energy savings achieved with Location-Aware Node-to-Node transmission in Ubicomp using Location Refresh Intervals".

Key terms: MAUC-Mobile and Ubiquitous Computing, SD- Standard Deviation, PV-Peak Value, PCSME-%CBR spending more energy.

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1. Introduction

1.1 Brief of Relays and Their Purposes.

Relays (retransmitters or antennae) have traditionally been used when communicating nodes are out of reach (long distance) or when communicating nodes transmit at low intensities (short distance). Relays can be surrogate devices in a MAUC environment and hence very much interest researchers. Purposes of Relays may include:

i. Help transmit messages to long distances to out of reach destinations.
ii. Help communicating devices to save energy for transmissions and retransmissions involved.
iii. Help in location-tracking for mobile nodes.
iv. Help avoiding a transmitting node from processing location awareness of destination node and hence render the work simpler and faster.

Specialised relay devices can be fixed or mobile. Other nodes can also serve as relays giving rise to ad hoc routing.

1.2 Scope of this study.

This study aims at finding trends of energy savings achievable when relays are used in different scenarios of varying numbers of relays. The results of this study are expected to serve for:

i. Understand the savings trends achievable with varying numbers of relays.
ii. Estimate the optimal relay densities that can be adopted.
iii. Estimate future optimal relay densities in cases of expansion, increases in node densities, changes in mobility and communication patterns etc, and formulate ready solutions to predictable situations.
iv. Better plan for placement of relays. Investigate which relays are important and to extent. Also, which relays can be omitted.
v. Understand types of relays to be used at different locations. Relays having high communications needs have to be more powerful. Those of lesser communications needs can have lesser powerful relays (continued use of old relays)

2. Experiment Design

Here, progresses from previous 2 papers [18,19] are made use of. A total of 25 sets of processing could be devised corresponding to the number of relays used. An algorithm for uniform positioning of relays has been used. CBR sending to nearest relay is considered for each packet. Energy spent is recorded and energy saved can be calculated. Energy saved can be negative in case the closest relay is further than the receiver nodes.

Processing for smaller number of relays take smaller time and for larger number of relays, more time is needed. Hence, due to excessive time being required, processing has been carried out for relay numbers 1 up to 16 and 25. These should be enough to observe trends concerned.

The following provisions have also been made:

i. Keep track of relay positions for each number of relays concerned.
ii. For each cbr, number of packets being transmitted to each relay.
iii. Summary of total amount of data transiting through each relay.

3. Results and observations.

<u>*3.1 Trends of Energy Savings against number of relays.*</u>

The work in this section, has been done over several iterations trying to fit the normal curves and other equations like cubic, square and exponential equations. After several iterations, the exponential equations have been found most fitting and parameters of equations reworked several times to get consistent results.

1. For 1 Relay.

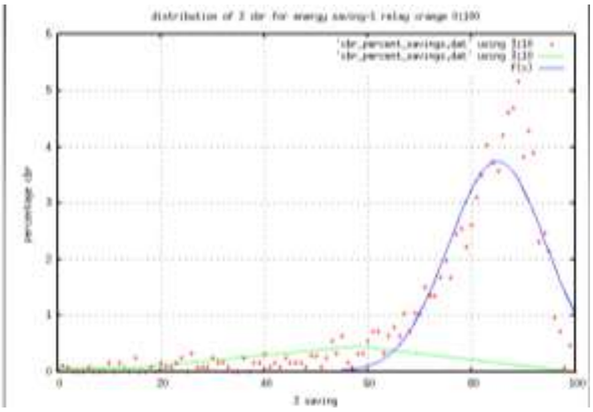

Fig 1: Savings achieved by cbrs- 1 relay

Most CBRs are achieving savings than compared to previous paper [18,19]. About 6.589% CBRs spend more energy and maximum recorded is 41 times more. Quite a lot of distribution have % savings between 20 and 60, suggesting that improvements are desirable. A good normal distribution is obtained with mean at 85%, PV at 5.15% and SD of 0.106662.

One centrally placed relay presents progress to previous paper [18] as concerns bigger positive skewness (mean changed from 67% to 85%) and slightly higher peak value. But since low % CBRs are being concerned, the strategy of only 1 relay is not of good enough return.

2. For 2 Relays.

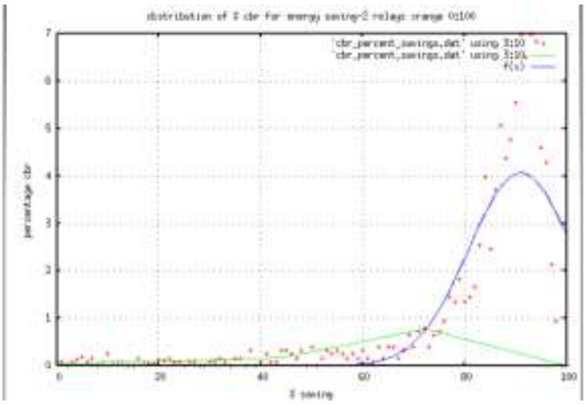

Fig 2: Savings achieved by cbrs- 2 relays

Mostly similar Observations as in (1) above. About 4.13% of CBRs spend more energy. Normal distribution is seen with mean 91, PV 6.985 and SD 0.0981716. Overall, using 2 relays, has not presented significant improvement over 1 relay.

3. For 3 Relays.

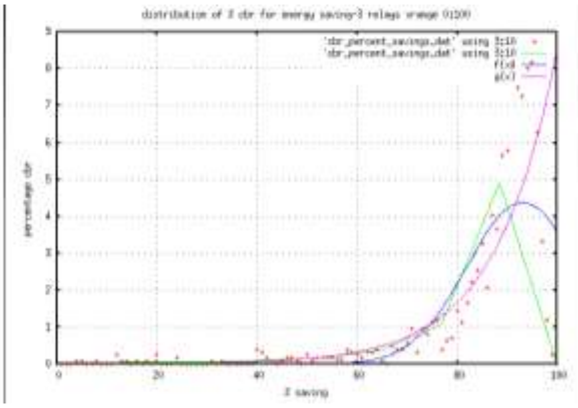

Fig 3: Savings achieved by cbrs- 3 relays

Many observations can correspond to (2) above. PCSME is reduced to 1.43 with worst case being 10.5 times high. Normal curve with mean 93 and PV 8.18 seem unconvincing. A suitable exponential equation obtained is

$g(x)=0.00818 * \exp(0.0818*(x-15))$

This gave rise to a hypothetic equation in the form

$g(x)=(0.1)*c * \exp(c*(x-d))$

where “c” is peak value of distribution and “d” is the % saving above which 97.5% of the CBRs are found.

4. For 4 Relays.

More observations confirming grounds of exponential distribution is available. PCSME is reduced to 0.794 but worst case remains at 10.5 times higher. Mean of distribution is at 95%, PV is at 13.89%. The exponential equation obtained corresponds to the hypothetic equation and is:

$g(x)=0.01389 * \exp(0.1389*(x-47))$

Note: Quite some CBRs achieve savings above mean.

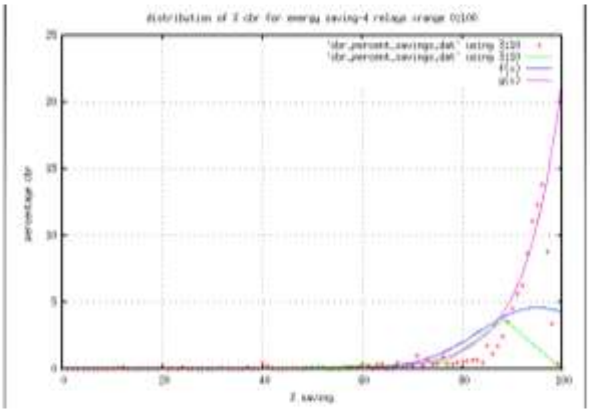

Fig 4: Savings achieved by cbrs- 4 relays

5. For 5 Relays.

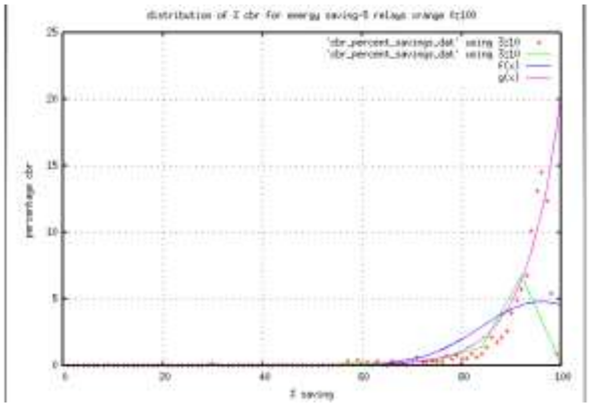

Fig 5: Savings achieved by cbrs- 5 relays

Mean is at 96% with PV 14.52. PCSME is at 1.19% with worst case at about 7 times higher. The exponential equation obtained is:

g(x)=0.01452 * exp (0.1452*(x-50))

Overall, an increase from 4 relays to 5, has not been a big improvement.

6. For 6 Relays.

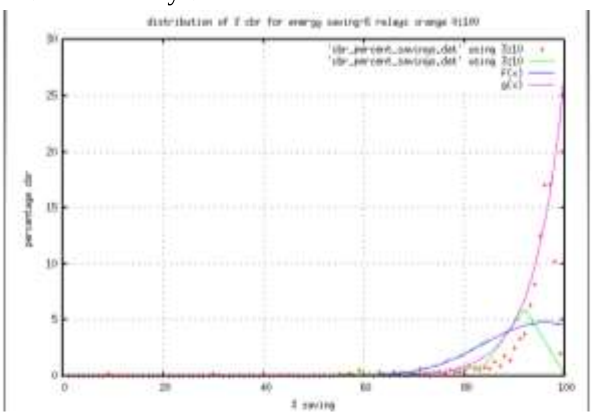

Fig 6: Savings achieved by cbrs- 6 relays

Mean is at 96% with PV 17.15. PCSME is 0.952% with worst case of 7 times higher. Exponential equation obtained is:

g(x)=0.01715 * exp (0.1715*(x-57))

Again, progress is not so commendable.

7. For 7 Relays.

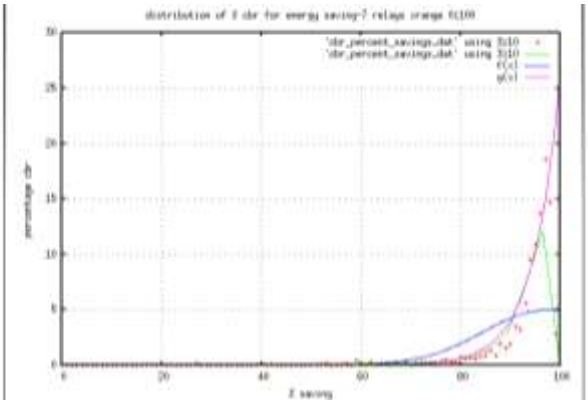

Fig 7: Savings achieved by cbrs- 7 relays

Mean is at 97% with PV 18.59.PCSME is 0.714 with worst case of 2.5 times higher. Exponential equation obtained is:

g(x)=0.01859 * exp (0.1859*(x-61))

There is progress but next section shows that with some additional relays, progress can be significantly better.

8. For 8 Relays.

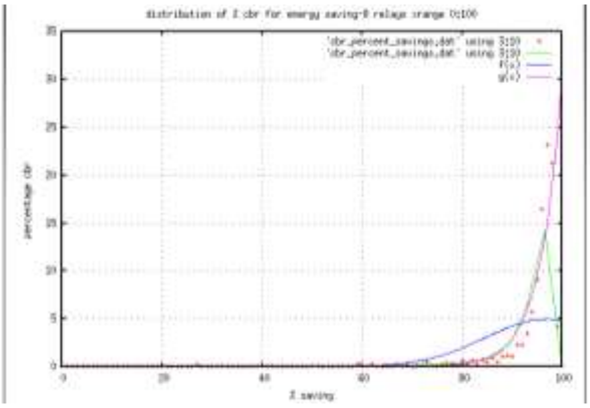

Fig 8: Savings achieved by cbrs- 8 relays

Mean is at 97% with PV 23.56%. PCSME is 0.556 with worst case of 2.5 times higher. The mean value is already very high and peak value has improved drastically. Exponential equation obtained is:

g(x)=0.02316 * exp (0.2316*(x-69))

This arrangement has been commendable.

9. For 9 Relays.

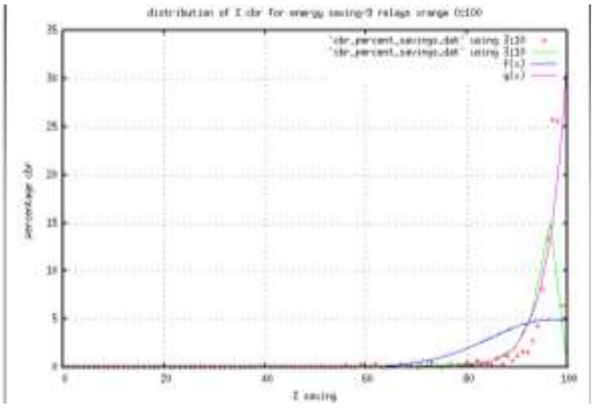

Fig 9: Savings achieved by cbrs- 9 relays

Mean is at 97% with PV 25.56. PCSME is 0.556 with worst case of 2.5 times higher. Exponential equation obtained is

$g(x)=0.02556 * \exp(0.2556*(x-72))$

Performance here is commendable, though a different arrangement of fewer relays could have been better.

10. For 10 Relays.

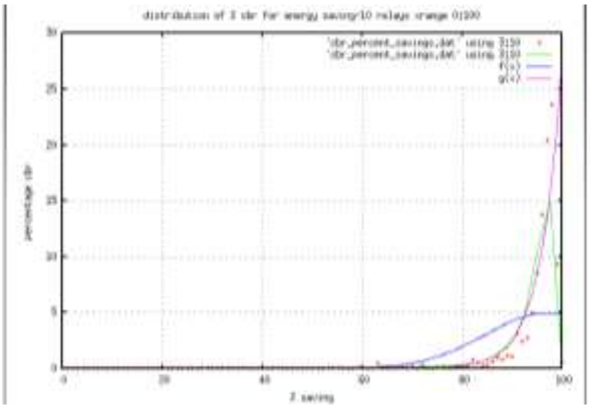

Fig 10: Savings achieved by cbrs- 10 relays

Mean is at 97% with PV 23.58. PCSME is 0.556 with worst case of 1.5 times higher. Equation obtained is:

$g(x)=0.02358 * \exp(0.2358*(x-70))$

There is a performance drop here giving more grounds for studying prominence of placements of relays.

11. For 11 Relays.

Mean is at 98% with PV 31.35. PCSME is 0.476 with worst case of 1.5 times higher. Equation obtained is:

$g(x)=0.03135 * \exp(0.3135*(x-76))$

There is performance improvement over 10 relays probably because of better placements of relays.

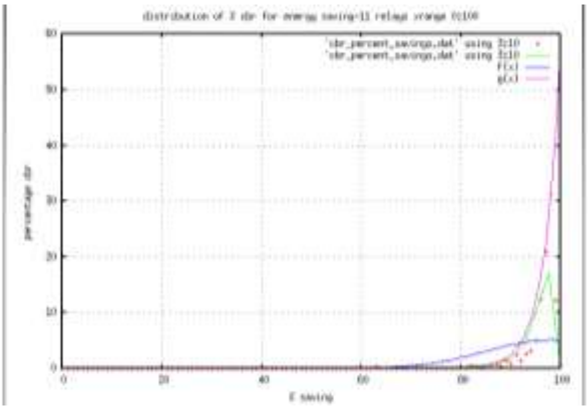

Fig 11: Savings achieved by cbrs- 11 relays

12. For 12 Relays.

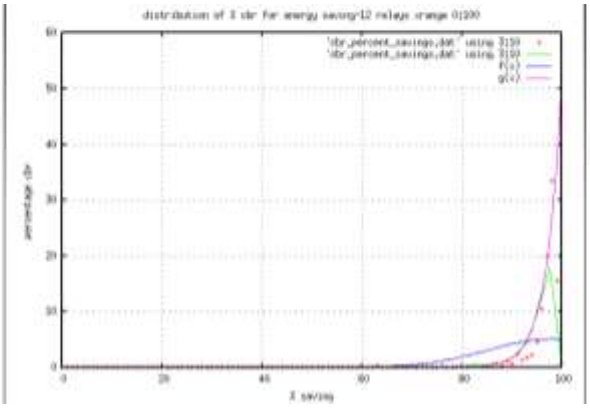

Fig 12: Savings achieved by cbrs- 12 relays

Mean is at 98% with PV 33.418. PCSME is 0.476 with worst case of 1.5 times higher. Equation obtained is:

$g(x)=0.033418 * \exp(0.33418*(x-78))$

13. For 13 Relays.

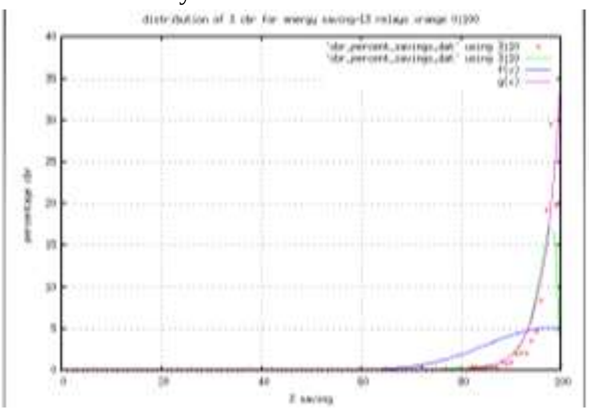

Fig 13: Savings achieved by cbrs- 13 relays

Mean is at 98% with PV 29.592. PCSME is 0.079 (very small) with worst case of 0.3 times higher. Equation obtained is

$g(x)=0.029592 * \exp(0.29592*(x-76))$

Again, a performance drop from previous situation due to decrease in uniformity of distribution of relays.

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14. For 14 Relays.

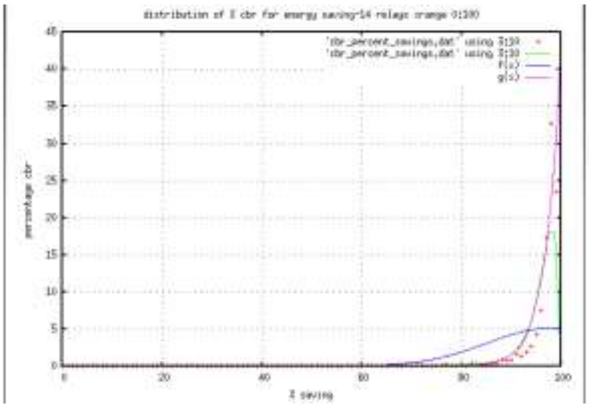

Fig 14: Savings achieved by cbrs- 14 relays

Mean is at 98% with PV 32.688. PCSME is 0.079 with worst case at 0.3 times higher. Exponential equation obtained is:

g(x)=0.032688 * exp (0.32688*(x-78))

Like for 11 relays, here also, ground for better placement of relays is felt important.

15. For 15 Relays.

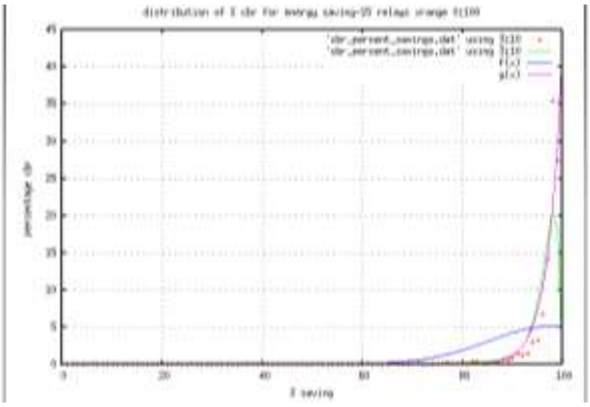

Fig 15: Savings achieved by cbrs- 15 relays

Mean is at 98% with PV 35.466. No CBR spends more energy. Exponential equation obtained is:

g(x)=0.035466 * exp (0.35466*(x-80))

This performance is commendable. Very few chances of spending more energy when relays are at 60m or less from each other. It could possibly be obtained with lesser relays at more prominent positions.

16. For 16 Relays.

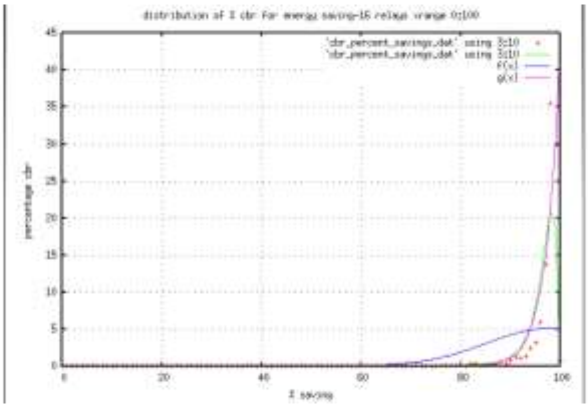

Fig 16: Savings achieved by cbrs- 16 relays

Mean is at 98% with PV 35.545%. No CBR has –ve energy savings. Exponential equation obtained is:

g(x)=0.035545 * exp (0.35545*(x-80))

Performance is commendable but low improvement from previous situation of 15 relays. The 16th relay is at a low prominent position.

17. For 25 Relays.

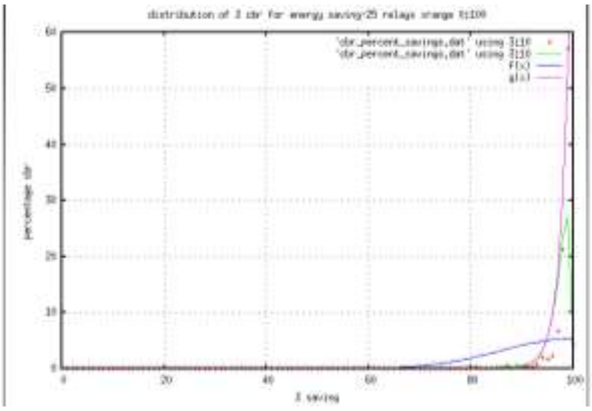

Fig 17: Savings achieved by cbrs- 25 relays

Mean is at 99% (seemingly the maximum) with PV of 57.121% (more than 50% of CBRs). All CBRs have made savings here. The equation obtained is:

g(x)=0.057121 * exp (0.57121*(x-87))

This performance is very commendable but cost of investment will be very high. Different arrangements of fewer relays may be better.

3.2 General Observations from section 3.1.

i. Using relays is definitely advantageous as use of only one centrally placed relay does already bring in a difference in measures of mean values.

ii. However, not all numbers of relays nor placements of relays seem to be worthy.

  a. Only 1 or 2 or 3 relays placements demonstrate a fairly normal distribution of savings experienced with peak value.

  b. As from 4 relays, the exponential distribution is observed. Here, relays are at 100 m away from edge of topo and next neighbouring relay.

Hence, it can be concluded that when relays are being set up in a topography, an arrangement where nodes would mostly be at less than 100 m from a relay is desirable as energy savings become of greater consequence.

iii. Values of mean and peak values show good progress as relays increase in number. However, for certain situations, incrementing number of relays bring a drop in performance (from 9 relays to 10, from 12 to 13 relays). This observation is coupled by another observation that incrementing the number of relays again brings very significant improvements. This has given enough grounds to devise studies about prominence of placements of relays.

iv. Studies of results as from 6 relays and more have given good performance levels which could have been reproduced by fewer relays. This same observation would apply for 17 relays onwards and hence study of only 25 relays is performed.

v. The exponential curve as per the hypothetic equation has been very suitably been applicable to all experiments above 2 relays

$$g(x)=(0.1)*c*exp(c*(x-d))$$

Hence, a study of variations of parameters c and d together with peak values is felt necessary.

<u>3.3 Study of Variations of Parameters.</u>

Following the hypothetic equation, the experiment results obtained are summarised in the following table. Index A-Num of relays, B-Mean value observed, C-PV at mean, D-value of d

A	B	C	D	A	B	C	D
1	85	5.15	-	10	97	23.58	70
2	91	6.985	-	11	98	31.35	76
3	93	8.18	15	12	98	33.418	78
4	95	13.89	47	13	98	29.592	76
5	96	14.52	50	14	98	32.688	78
6	96	17.15	57	15	98	35.466	80
7	97	18.59	61	16	98	35.545	80
8	97	23.16	69	25	99	57.121	87
9	97	25.56	72				

1. Mean Values of Distribution.

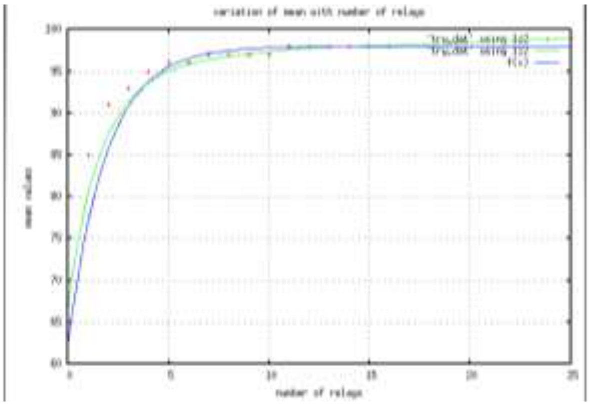

Fig 18:Mean savings against num of relays.

Mean is at a high value – 85% and increases drastically for 2 till 5 relays and then tends to flatten asymptotically to 99% at 25 relays. Values of means being high, there is no need to look for efforts to improve these high values. Care should be taken, in case of location tracking done at refresh intervals, for the value of the means not to drop too much.

The curve obtained is convincing as an inverse exponential distribution except for relays 1,2 and 3 where exponential distribution had not fitted completely well. Equation obtained is

$F(x)=-35.545 * exp (-35.545*(3/2)*x)+98$

"35.545" is the peak value at mean for 16 relays and corresponding mean is at 98. This also implies that the means are tending to stabilise at 98. The value of 3 in (3/2) may suggest better applicability of model beyond 3 relays.

This graph can be used to predict values of mean obtainable for different numbers of relays in a topography of 300 x 300 m^2 without the need for further simulations.

2. Peak Values (PV) at mean.

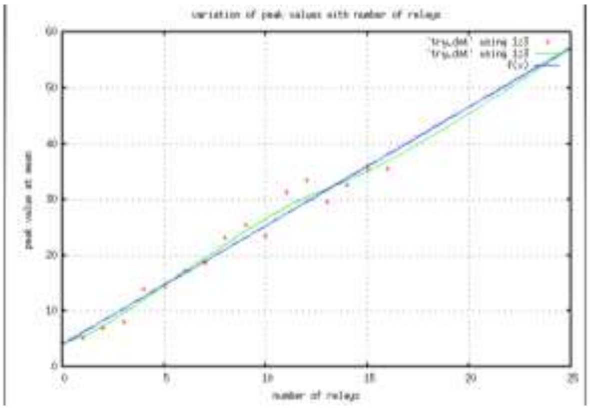

Fig 19: PV at mean against num of relays.

This model is most useful to guide designers on the target peak value at mean to reach for energy savings and attempt the corresponding number of relays as a starting point and improve on their placements.

The peak values seem to increase linearly with respect to number of relays

F(x)=2.12703 * x + 4.10853

The deviations of the plots from the line of best fit may suggest impacts of prominence of placements of relays.

This prediction model can be used to estimate the maximum number of relays that can be needed to achieve a certain performance level and rework placements of lesser relays to reach that performance.

This model can also be used in cost containment when investment for relays will be decided.

3. Variations of values of d.

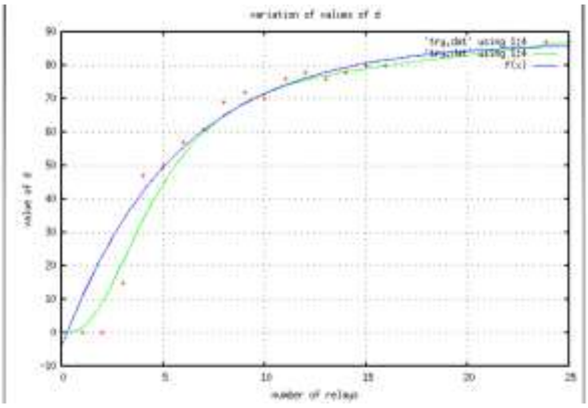

Fig 20:Values of d against num of relays.

The plots obtained are very close to its smooth bezier and also depict inverse exponential growth. For relays 1,2, and 3 the deviation can again be seen.

F(x)=1.5*-35.545*exp(-35.545* (1/2)*(x-3)) + 87

We recall exponential fits best beyond 3 relays. The above model can be used to predict values of d in the hypothetic equation.

g(x)=(0.1)*c*exp(c*(x-d))

The values of d thus obtained can serve as a first iterations and reworking can be done over very few numbers of iterations to obtain appropriate equation governing savings achievable in this topography.

4. Investigation into Prominence of Relays

4.1 Introduction to Prominence.

Placement of relays is of very big impact. Adding new relays at wrong placement may not have significant return on investment. Identifying most and least important relays is very important and can serve in building new/better optimal arrangements of relays.

Additional information requirements identified in section 2 have been made use of.

4.2 Summary of Results.

As number of relays increase, the % data transits through each relay tends to decrease. However, the %data transit is not the same for each relay. Some relays tends to have more importance than others, e.g. for 6 relays 1 relay has twice more importance than the least important one, for 9 relays 3.5 times, for 14 relays it is 4.49 times, 16 relays at 4.90 times.

4.3 Procedures for Finding Optimal numbers of most Prominent Relays.

i. Start from a maximum uniform distribution scenario like 6, 9, 12, 16, 20 or 25 relays. It would be mostly in the form n^2 or n(n-1).
ii. Perform processing for energy savings achieved in the scenario and retrieve amount of data transiting through each relay.
iii. Following part (ii) above, % prominence of each relay in the scenario is calculated.
iv. Then the descending order of the relay prominence is arranged.
v. From part iv above, reduction of lesser important relays can be made. The reduced number of relays should most probably be equal or above the previous number of maximum uniform distribution. E.g if in step iv above, 25 relays were arranged, reduction until 20 relays can be achieved quite safely. Further reduction can be attempted on a trial basis and energy savings observed.
vi. Simulation experiments for finding energy savings possible from the reduced number of relays can be run and performance evaluated.
vii. Decisions of relays placements and future enhancement plans can follow from results from above steps.

5. Investigation into Optimised number of Relays

Following study in section 4.3 above, 11 sets of optimal relays had been identified and studied. Mostly, these relays are located along the central axes of the topography.

5.1 Trends of Energy Savings.

1. For 4 Optimal Relays.

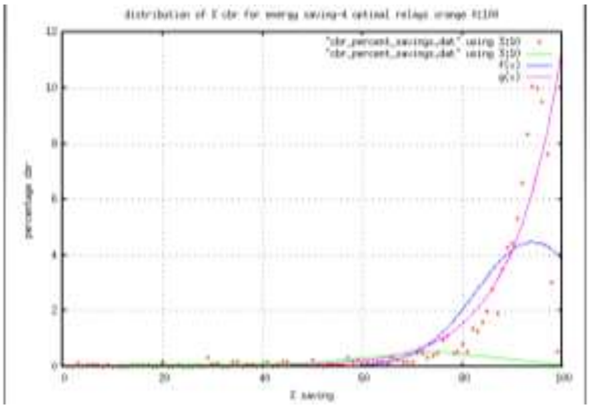

Fig 21:Trends of energy savings– 4 opt relays.

Mean is at 94% and PV at mean is 10.06. PCSME is 3.016 with worst case at 24.6 times higher. Exponential equation obtained is:

g(x)= 0.01006 * exp (0.1006*(x-30))

The experiment (and all successive experiments) proves applicability of exponential model. Prominence ratio discrepancies is reduced but further optimisations may be possible.

2. For 5 Optimal Relays.

Mean is at 96% and PV at mean is 16.19. PCSME is 2.06 with worst case at 20.2 times higher. Equation obtained is

g(x)= 0.01619 * exp (0.1619*(x-56))

This optimisation is <u>clearly more successful</u> and prominence descrepancies have very much been levelled.

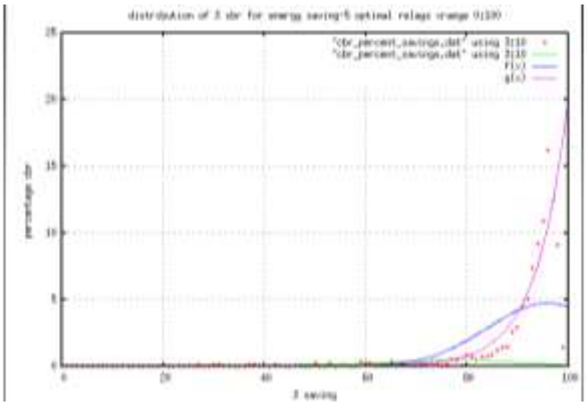

Fig 22:Trends of energy savings– 5 opt relays.

3. For 8 Optimal Relays.

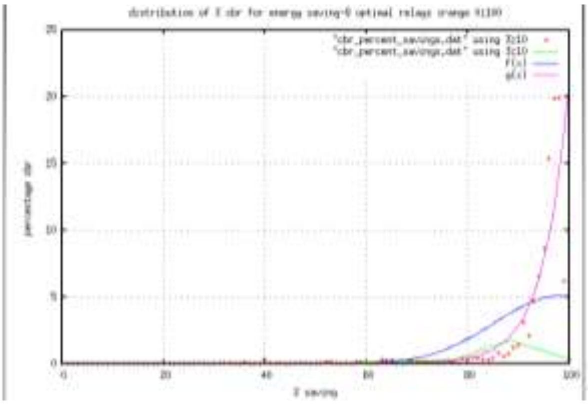

Fig 23:Trends of energy savings– 8 opt relays.

Mean is at 98% and PV at mean is 19.92. PCSME is 0.95% with worst case at 11.5 times higher. Exponential equation obtained is

g(x)= 0.01992 * exp (0.1992*(x-65))

Prominence discrepancies show possibility of improvements.

4. For 9 Optimal Relays.

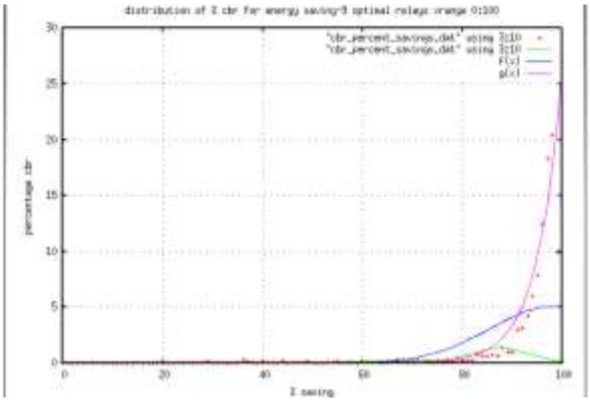

Fig 24:Trends of energy savings– 9 opt relays.

Mean is at 98% and PV at mean is 20.48. PCSME is 0.95% with worst case at 9 times higher. Exponential equation obtained is

g(x)= 0.02048 * exp (0.2048*(x-65))

Prominence discrepancies show possibility of improvements.

5. For 10 Optimal Relays.

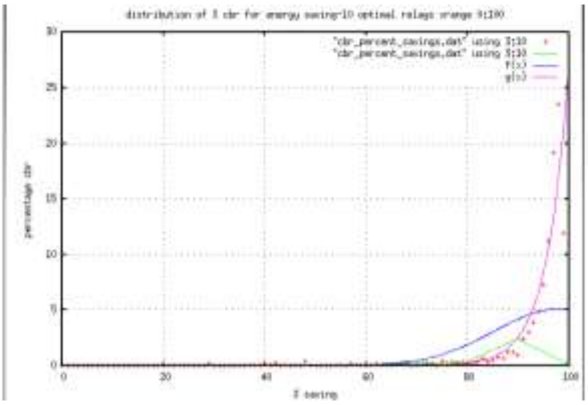

Fig 25:Trends of energy savings– 10 opt relays.

Mean is at 98% and PV at mean is 23.50. PCSME is 0.64% with worst case at 9 times higher. Exponential equation obtained is

g(x)= 0.02350 * exp (0.2350*(x-70))

Possibility of better arrangements by trial and error is open.

6. For 11 Optimal Relays.

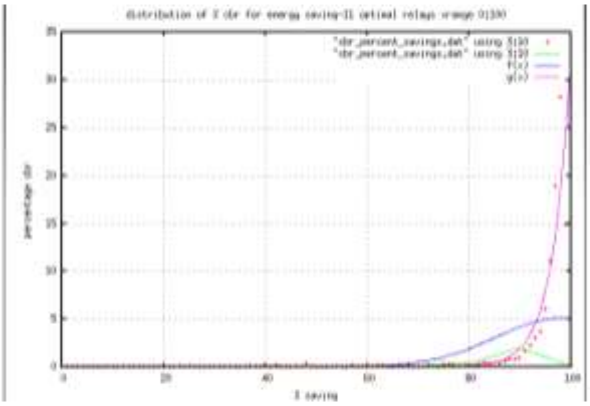

Fig 26:Trends of energy savings– 11 opt relays.

Mean is at 98% with PV at 28.18. PCSME is 0.64 with worst case at about 9 times higher. Equation obtained is

g(x)= 0.02818 * exp (0.2818*(x-75))

Prominence ratio disparities show possibility of better re-arrangement of relays.

7. For 12 Optimal Relays.

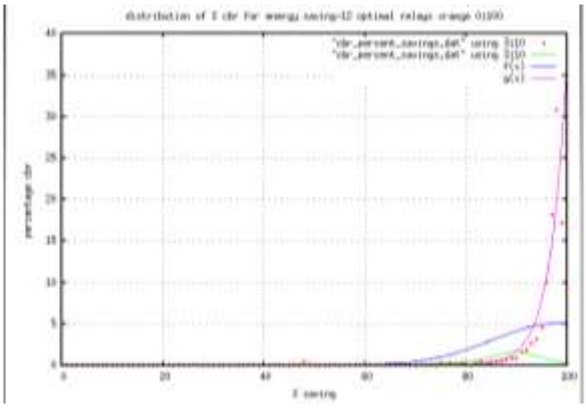

Fig 27:Trends of energy savings– 12 opt relays.

Mean is at 98% with PV at 30.80. PCSME is 0.64 with worst case at about 9 times higher. Equation obtained is

g(x)= 0.03080 * exp (0.3080*(x-77))

Again, better arrangement is possible.

8. For 13 Optimal Relays.

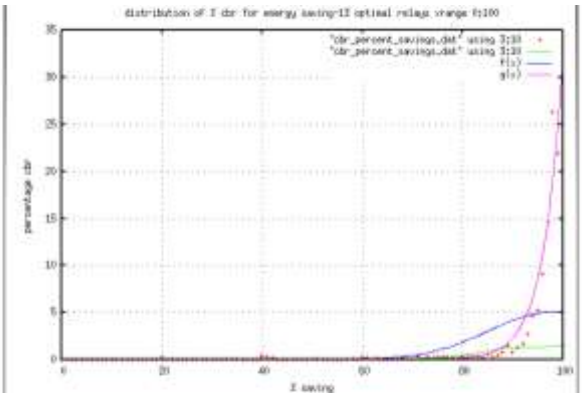

Fig 28:Trends of energy savings– 13 opt relays.

Mean is at 98% with PV at 26.34. PCSME is 0.56 with worst case at about 10.5 times higher. Equation obtained is

g(x)= 0.02634 * exp (0.2634*(x-73))

This attempt to optimisation is not so successful and prominence discrepancies have not so much improved.

9. For 14 Optimal Relays.

Mean is at 98% with PV at 28.64. PCSME is 0.56 with worst case at about 10.5 times higher. Equation obtained is

g(x)= 0.02864 * exp (0.2864*(x-75))

Again, it is not so successful.

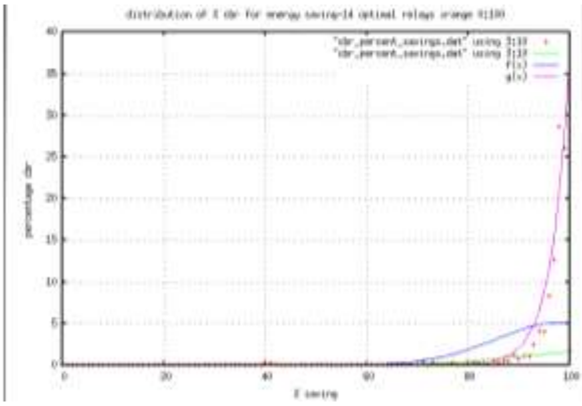

Fig 29:Trends of energy savings– 14 opt relays.

10. For 15 Optimal Relays.

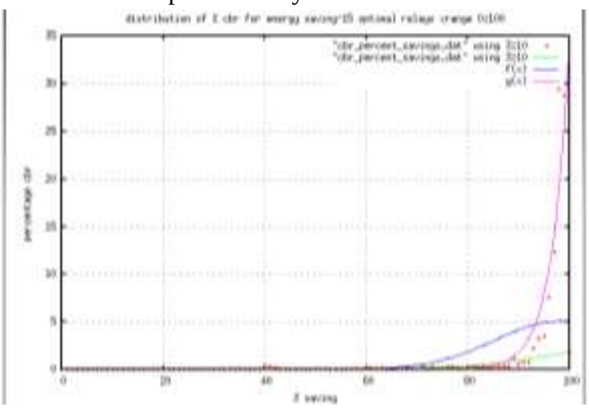

Fig 30:Trends of energy savings– 15 opt relays.

Mean is at 98% with PV at 29.43. PCSME is 0.56 with worst case at about 10.5 times higher. Equation obtained is

g(x)= 0.02943 * exp (0.2943*(x-76))

Rearrangement may be attempted but margin of improvement will be small.

11. For 16 Optimal Relays.

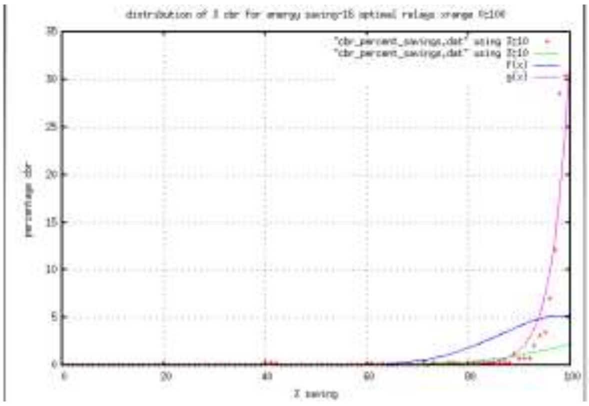

Fig 31:Trends of energy savings– 16 opt relays.

Mean is at 99% with PV at 30.40. PCSME is at 0.56 with worst case at about 10.5 times higher. Equation obtained is:

g(x)= 0.03040 * exp (0.3040*(x-77))

This attempt has been a very successful optimisation.

5.2 Observations and Conclusions.

This section of study has been very valuable. All attempts of optimisation have not been completely successful but quite interesting observations can be drawn:

1. **Confirmation of exponential model**, despite removal of some least prominent relays, to the form.

   g(x) = 0.1 * c * exp(c*(x-d))

   Values of c and d might have regressed but overall, the exponential model holds applicable.
2. Confirmation of **better suitability** of relays along **central locations** (axes).
3. **All optimised arrangements** can serve as **good starting points** for future enhancements. This is supported by the fact that mean values have mostly not regressed at all.
4. **Study of Prominence ratios** does give indication of further optimisation by trial and error. This may be subjective to the designer's choice and topography details affecting movement patterns and communication scenarios.
5. Significance of number of relays.

   For relays up to 16 in a topography of 300x300, each relay, even the least prominent ones, may bring very significant contribution in the model of energy savings achieved. They do affect the mean value and specially the peak values at mean. The technique of optimisation devised by omitting least prominent relays will be more successful if starting from high numbers of relays (e.g. 40 or 50) and then reduce or combine least prominent ones.
6. Omission Criteria for Relays

   We need a way to decide what prominence level allows a relay to be omitted. After some trial and errors, the following method is being put forward:

   Step 1: Calculate Expected % data transits E(%dt), following the number of relays being used (n).

   E(%dt) = 100% / n.

   Step 2: Establish threshold value of E(%dt), using a chosen threshold fraction/percentage.

   Threshold value E(%dt)= threshold fraction *E(%dt)= 0.75 * *E(%dt).

   Step 3: Identify relays that can be omitted, i.e. relays having % data transits less than the threshold value.

6. Conclusion.

This piece of study is a follow-up from 2 previous papers [18,19]. This conclusion, hence, adds to the previous conclusions. Again, the nature of this piece of study has been to study several sets of experiments and hence explains the vast number of graphs obtained. (without graphs, this paper is of 9 pages).

This piece of research has investigated the effect of varying numbers of uniformly placed relays on energy savings achieved by nodes in a MAUC environment. The model which has very convincingly been applicable is the exponential model of equation

g(x) = 0.1 * c * exp(c*(x-d))

Investigation into the variation of the parameters also have been done and appropriate models have been formulated. These models can be used for prediction in a MAUC topography and also add a reference against which some reliability features of a MAUC can be rated. It may also help in formulation of appropriate metrics and shape the development of new architecture support in a MAUC environment.

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