International Journal of Advance in Computer Science & its application – IJCSIA 2018
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Volume 7 : Issue 2 [ISSN : 2250-3765] - Publication Date: 25 June , 2018

Trend Analyses of Critical Values Obtained for Overall Node Energy Savings Achievable in Ubicomp MANETs Using Location-Aware Transmission.

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Abstract **– Two promising avenues in the field of ubicomp are MANET transmission strategies and location-aware transmission [1-46]. The merging of these two fields is bound to lead to betterment in ubicomp and justifies the amounts of research involved. One factor, over which success of these strategies depend, is correct protocols designs. Current research attempts are claimed to be unsuitable for "correct the first time implementations" [84] because present methods for protocol design are heuristic in nature. Middleware services and applications are also subject to optimisation methods [85]. Novel network architecture for ubicomp is also felt needed to suit QoS and adaptability to node densities [86]. A longer term objective in this direction is to achieve realism in design and evaluation of wireless routing protocols [87]. Such direction of research will also entail more precise features for predictability in ubicomp. Achieving realism is a tedious process since it involves realism in every aspect related to ubicomp. One such aspect was studied in a previous research [15] to assess the trend of energy savings achievable by overall nodes (OES) in location-aware MANET transmission, followed by the study of trends for each OES parameter of equations [31].**

To upgrade realism in knowledge of these trends, in this paper, the successive questions is put forward as: "What are the observable critical values in OES trends? What are the trends of variation observable within each critical value for metric OES over varying node densities?"

Such knowledge will indeed aid designers in developing more realistic ubicomp scenarios over which new ubicomp features and protocols can be tested more realistically. This work follows-up from previous work [1-46].

Key terms: Ubicomp- Ubiquitous Computing, MAUC- Mobile and Ubiquitous Computing, ES- Energy Savings, OES- Overall ES, MANET- Mobile Adhoc Network, CBR- Constant Bit Rate, CV- Critical Value.

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1. Introduction

Many factors [2] affect energy consumption in MAUC, among which type of transmission and node density remain significant ones. In a previous work [15], an attempt was made through simulation experiments, to find a particular trend/model which depicts energy savings that can be reached by overall nodes in MAUC (OES) to rate the effectiveness of location-aware MANET transmission strategies compared to the theoretical/empirical models derived in simulations. The model put forward for the metric OES was the normal distribution model of form:

```
F(x)=b*(1/(a*sqrt(2*pi)))*exp(-(x-c)^2/2*a*a)
```

The study which followed [31] was mathematical modelling of the trends of the three parameters of equation obtained. It was stated that [31] such knowledge will help designers to better understand evolution and predictability of ubicomp environments. To assist in such aspect, a platform of realistic simulation scenarios over which testings of newly developed components, including communication protocols, can be undertaken conveniently.

The next level of research that is required for the metric OES is identifying certain key critical values obtained during experimentations and formulating the corresponding mathematical trend of variations over varying node densities for each critical value. Eleven such critical values have been obtained.

The key contribution of this paper is the establishment of the trend of variation covering node numbers 7 until 56, for each of the eleven critical values observed for metric OES introduced in previous papers [15, 31]. Availability of such data will certainly help ubicomp designers to better understand the evolution and predictability of ubicomp behaviour and derive more authentic simulation scenarios over which novel communication protocols being designed could be validly tested. The rest of this paper is organised as follows: section 2- OES Critical Values, section 3- Critical Values Trend Analyses- Metric OES, section 4- Conclusion and References.

2. OES Critical Values.

2.0 Critical Values Identified.

Eleven critical values have been identified as follows: Column headings are: C1→OES Critical Value, C2→

Meaning of OES Critical Value, C3→ Corresponding figure number for the OES Critical Value.

C1	C2	C3
1	Smallest value of OES noted.	1
2	%CBR at smallest value of OES.	2
3	Highest value of OES noted.	3
4	%CBR at highest value of OES.	4
5	%CBR at negative value of OES.	5
6	%CBR at OES value of 0.	6
7	%CBR at OES greater than 0.	7
8	%CBR at modal value of OES.	8
9	%CBR with OES value below modal value	9
10	95% CBR with OES value as from	10
11	%CBR in OES range -500 until 0	11

Table 1: OES Critical Values

2.1 Experimental Critical Values Obtained.

The values obtained in experiments are summarised below. Values have been rounded to a maximum of 9 decimal places. Column heading NN → Node Number.

NN	CV1	CV2	CV3	CV4	CV5
7	-1392	0.07936507	90	0.079365079	11.666666667
8	-1392	0.07959248	90	0.079365079	11.668258516
9	-1183	0.07936507	88	0.174603175	12.380952381
10	-1203	0.07936507	89	0.079365079	13.968253968
11	-1171	0.07936507	88	0.158730159	14.682539683
12	-1203	0.07936507	88	0.079491256	15.739268680
13	-1218	0.01587301	86	0.158730159	16.031746032
14	-1288	0.03174603	86	0.158730159	16.428571429
15	-1683	0.04761904	86	0.079365079	17.380952381
16	-2314	0.01587301	86	0.079365079	17.460317460
17	-3549	0.01587301	87	0.079365079	18.571428571
18	-4358	0.01587301	86	0.079365079	19.761904762
19	-3904	0.01587301	86	0.079365079	19.523809524
20	-4015	0.01587301	87	0.079365079	19.285714286
21	-1784	0.01587301	85	0.079365079	19.761904762
22	-2878	0.01587301	85	0.079365079	19.761904762
23	-3818	0.01587301	85	0.158730159	20.238095238
24	-3147	0.01587301	85	0.158730159	19.920634921
25	-2276	0.01587301	85	0.079365079	20.079365079
26	-3228	0.01587301	83	0.158730159	21.190476190
27	-3210	0.01587301	83	0.158730159	20.968253968
28	-3128	0.01587301	82	0.079365079	21.825396825
29	-3178	0.01587301	83	0.079365079	22.063492063
30	-3223	0.01587301	81	0.238095238	22.777777778
31	-1628	0.01587301	84	0.079365079	21.349206349
32	-1673	0.01587301	84	0.079365079	21.904761905
33	-1679	0.01587301	84	0.079365079	22.222222222
34	-1684	0.01587301	83	0.079365079	22.539682540
35	-1701	0.01587301	83	0.079365079	22.619047619
36	-1771	0.01587301	81	0.079365079	23.253968254
37	-1593	0.03175107	82	0.158755358	23.495792983
38	-1693	0.03175107	82	0.158755358	23.650793651
39	-1716	0.03175107	83	0.079365079	24.285714286
40	-1614	0.03175107	82	0.158730159	24.206349206
41	-1590	0.07936507	82	0.158730159	24.365079365
42	-1933	0.06349206	82	0.079365079	23.968253968
43	-1506	0.07936507	83	0.079365079	24.523809524
44	-1483	0.03176620	82	0.158831004	24.205844981
45	-1659	0.01587301	83	0.079365079	24.285714286
46	-1520	0.07936507	83	0.079365079	24.603174603
47	-1520	0.07936507	83	0.079365079	24.206349206
48	-2501	0.07936507	84	0.079365079	24.682539683
49	-2421	0.07936507	83	0.079365079	25.158730159
50	-3138	0.01587301	81	0.079365079	25.174603175
51	-3458	0.01587301	81	0.079365079	25.634920635
52	-4908	0.01587301	81	0.079365079	26.111111111
53	-4915	0.01587301	81	0.079365079	26.190476190
54	-5715	0.01587301	81	0.079365079	25.873015873
55	-5683	0.01587301	82	0.079365079	26.190476190
56	-5101	0.01587301	81	0.079365079	25.634920635

Table 2a: Experimental Critical Values Obtained(1)

NN	CV6	CV7	CV8	CV9
7	0.07936507	88.25396825	2.69841269	73.01587301
8	0.07959248	88.25214899	2.76981852	72.95447309
9	0.23809523	87.38095238	2.61904761	66.96825396
10	0.07936507	85.95238095	2.28571428	66.76190476
11	0.07936507	85.23809523	2.41269841	76.55555555
12	0.07949125	84.18124006	2.46422893	61.84419713
13	0.31746031	84.04761904	2.25396825	61.11111111
14	0.31746031	83.25396825	2.15873015	55.47619047
15	0.23809523	82.38095238	3.00000000	68.17460317
16	0.39682539	82.38095238	2.30158730	82.61904761
17	0.52380952	80.90476190	2.19047619	50.98412698
18	0.53968254	79.69841269	2.69841269	75.15873015
19	0.23809523	80.23809523	2.44444444	54.85714285
20	0.23809523	80.47619047	2.22222222	72.06349206
21	0.47619047	79.76190476	2.22222222	68.80952381
22	0.39682539	79.84126984	2.38095238	65.00000000
23	0.23809523	79.52380952	2.38095238	54.84126984
24	0.23809523	79.84126984	2.30158730	76.66666666
25	0.23809523	79.68253968	2.36507936	63.66666666
26	0.39682539	78.41269841	2.06349206	44.20634920
27	0.30158730	78.73015873	2.25396825	61.63492063
28	0.31746031	77.85714285	2.93650793	76.26984127
29	0.31746031	77.61904761	2.38095238	65.71428571
30	0.07936507	77.14285714	2.25396825	69.92063492
31	0.71428571	77.93650793	2.22222222	78.01587301
32	0.66666666	77.42857142	2.30158730	73.17460317
33	1.00000000	76.77777777	2.30158730	72.14285714
34	0.47619047	76.98412698	2.26984127	80.87301587
35	0.79365079	76.58730158	2.19047619	73.17460317
36	0.63492063	76.11111111	2.30158730	78.01587301
37	0.44451500	76.05969201	2.38133037	71.18590252
38	0.39682539	75.95238095	2.36507936	80.49206349
39	0.31746031	75.39682539	2.30158730	66.50793650
40	0.55555555	75.23809523	2.20634920	67.07936507
41	0.42857142	75.20634920	2.68253968	67.38095238
42	0.31746031	75.71428571	2.25396825	72.74603174
43	0.15873015	75.31746031	2.69841269	64.28571428
44	0.23824650	75.55590851	2.54129606	56.73443456
45	0.39682539	75.31746031	2.22222222	57.69841269
46	0.15873015	75.23809523	2.22222222	65.55555555
47	0.39682539	75.39682539	1.98412698	78.01587301

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Volume 7 : Issue 2 [ISSN : 2250-3765] - Publication Date: 25 June , 2018

48	0.41269841	74.90476190	2.06349206	63.09523809
49	0.39682539	74.44444444	2.00000000	70.14285714
50	0.55555555	74.26984127	2.06349206	70.79365079
51	0.47619047	73.88888888	2.61904761	69.04761904
52	0.39682539	73.49206349	2.04761904	66.03174603
53	0.31746031	73.49206349	2.12698412	71.96825396
54	0.31746031	73.80952381	2.14285714	66.11111111
55	0.15873015	73.65079365	2.49206349	66.34920634
56	0.50793650	73.85714285	2.26984127	68.44444444

Table 2b: Experimental Critical Values Obtained(2)

NN	CV10	CV11
7	-68	11.190476190
8	-69	11.190703598
9	-79	11.825396825
10	-98	13.253968254
11	-112	13.968253968
12	-126	14.864864865
13	-122	15.079365079
14	-130	15.555555556
15	-142	16.507936508
16	-139	16.587301587
17	-147	17.539682540
18	-151	18.888888889
19	-159	18.571428571
20	-163	18.095238095
21	-178	18.809523810
22	-176	18.492063492
23	-183	18.809523810
24	-205	18.571428571
25	-184	18.571428571
26	-230	19.365079365
27	-230	19.301587302
28	-232	20.158730159
29	-227	20.253968254
30	-231	21.111111111
31	-200	19.841269841
32	-198	20.158730159
33	-213	20.238095238
34	-207	20.634920635
35	-213	20.730158730
36	-249	21.587301587
37	-238	21.511351008
38	-240	21.746031746
39	-242	22.460317460
40	-257	22.460317460
41	-262	22.619047619
42	-249	22.539682540
43	-241	23.095238095
44	-238	22.538119441
45	-236	22.619047619
46	-234	23.095238095
47	-243	22.698412698
48	-252	23.253968254
49	-257	23.492063492
50	-218	23.666666667
51	-225	23.809523810
52	-221	24.126984127
53	-227	24.047619048
54	-243	23.888888889
55	-238	24.206349206
56	-240	23.809523810

Table 2c: Experimental Critical Values Obtained(3)

3. Critical Values Trend Analyses- Metric OES.

3.0 General Procedure Adopted.

The tabulated data for each CV for metric OES is plotted onto gnuplot over Linux. Graphical analysis using smooth bezier support and "Fit" command is performed. General observations, for each such graph obtained is reported. Several equations of fit have been tried and a summary is reported for each OES critical value. Ultimately, for CV2 and CV4, choice is based on flat values and for other CVs, choice is based on value of least reduced chi-square and secondly on most plausible extendability produced at node numbers 80, 100 and 120. Finally, the values of parameters for each equation of each OES critical value is also noted.

3.1 Trend Analysis – OES CV1.

The curve obtained here appears oscillating along a mildly decreasing straight line.

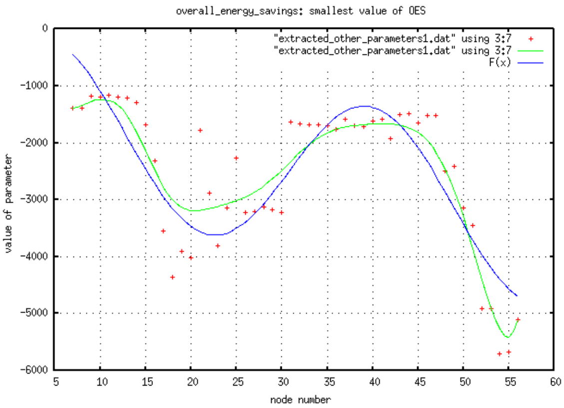

Figure 1: OES Critical Value 1

After lots of trials, the following equation of best fit is put forward.

```
F(x) = (a*sin(b*(x-c)) + d*x + f
```

Ch_sq = 445 162 F(80) = -3 112.936 568 812

F(100)=-5 498.980 636 100 F(120)=-5 361. 807 649 708

The parameters of best fit are:

a = 1 425 , b = 0.174 897 , c = 30.863 6 , d = -34.114 2 , f = -1 436.32

3.2 Trend Analysis – OES CV2.

The plots appear to be taking very discrete values and mostly the following is put forward.

$$F(x) = \begin{cases} 0.079 & 7 \le x \le 15 \\ 0.015\,8 & 16 \le x \le 40 \\ 0.079 & 41 \le x \le 49 \\ 0.015\,8 & x \ge 50 \end{cases}$$

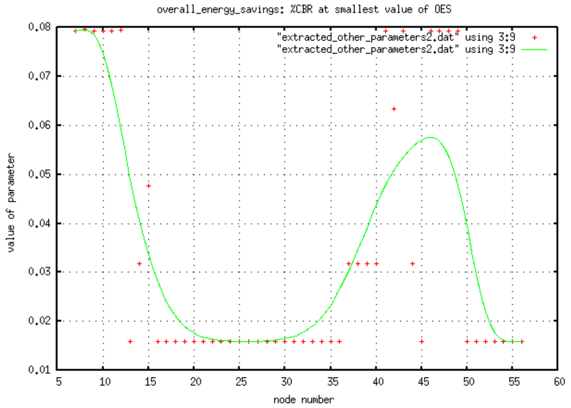

Figure 2: OES Critical Value 2

3.3 Trend Analysis – OES CV3.

The curve obtained here mostly depicts a decreasing tendency at a decreasing rate.

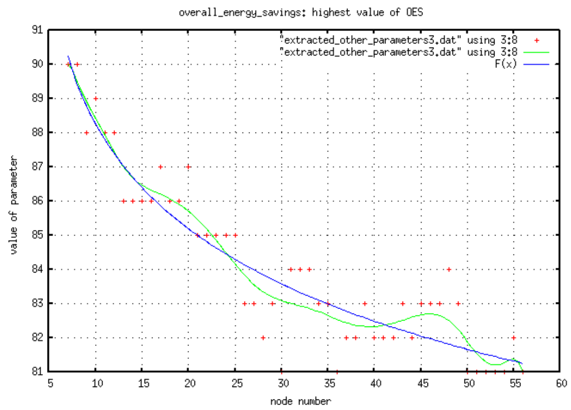

Figure 3: OES Critical Value 3

The potentially applicable equations are:

1. $F(x)= a/ \log((b*x) + c)$

   Ch_sq =0.904 451 F(80) = 79.673 562 914
   F(100) = 78.816 374 509 F(120) = 78.127 963 934

2. $F(x)= a/ \log((b*x) + (c*x^{1}))$

   Ch_sq =0.889 077 F(80) = 79.867 714 129
   F(100) = 79.060 187 887 F(120) = 78.412 413 324

3. $F(x) = a/ \log((b*x) + (c*x^{-1}))$

   Ch_sq =0.879 814 F(80) = 79.990 451 866
   F(100) = 79.221 202 808 F(120) = 78.603 996 668

4. $F(x) = a/\log((b*x) + (c*x^{-1.1}))$

   Ch_sq =0.889 333 F(80) = 79.867 602 921
   F(100) = 79.058 473 598 F(120) = 78.409 438 834

Choice of best fit for OES Critical Value 3

The equation in part 3 above was selected because of smallest reduced chi-square value obtained and good extendability. The parameters obtained for best fit are: a = 1 841.97 , b= 1.253 5(e^{+08}) , c= -1.014 21(e^{+09})

3.4 Trend Analysis – OES CV4.

Most plots (36 out of 50, i.e. 72 %) have stabilised at 0.08. Hence it is put forward with 72% confidence, that for any node number

$$F(x) = 0.08$$

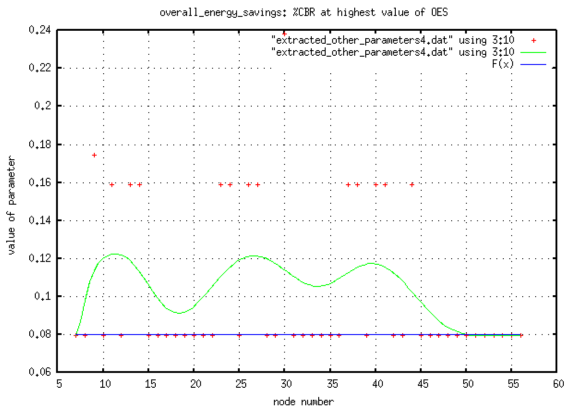

Figure 4: OES Critical Value 4

3.5 Trend Analysis – OES CV5.

The curve obtained here tends to increase at a decreasing rate. A minor oscillation of a negligible amplitude is also noted.

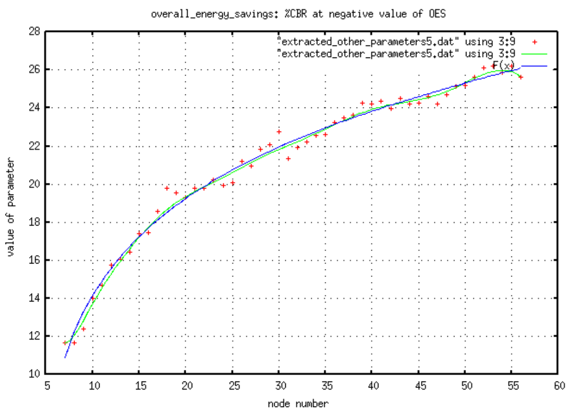

Figure 5: OES Critical Value 5

The potentially applicable equations are:

1. $F(x)= a/ \log((b*x) + c) + d$

   Ch_sq = 0.205 587 F(80) = 28.256 059 529
   F(100) = 29.643 572 902 F(120) = 30.770 978 603

2. $F(x)= a/ \log((b*x)+c) + (d*x)$

   Ch_sq = 0.205 873 F(80) = 28.174 796 864
   F(100) = 29.504 343 610 F(120) = 30.566 386 182

3. $F(x)= a/ \log((b*x)+c) + (d*x^{2})$

   Ch_sq = 0.205 418 F(80) = 28.404 420 170
   F(100) = 29.952 966 180 F(120) = 31.288 858 391

4. $F(x)= a/ \log((b*x)+c) + (d*x^{3})$

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Ch_sq = 0.204 943 F(80) = 28.655 500 222

F(100) = 30.583 217 972 F(120) = 32.541 433 350

5. $F(x) = a/\log((b*x)+c) + (d*x^4)$

Ch_sq = 0.204 59 F(80) = 28.971 851 041

F(100) = 31.634 856 333 F(120) = 35.118 801 633

6. $F(x) = a/\log((b*x)+c)+(d*x^{4.3})$

Ch_sq =0.204 506 F(80) = 29.087 856 884

F(100) = 32.084 888 421 F(120) = 36.358 262 107

Choice of best fit for OES Critical Value 5

The equation in part 6 above has been selected because of smallest reduced chi-square value obtained and good extendability. The parameters obtained for best fit are: a = 5.854 15 , b= 1.566 88 , c= -4.555 75 , d= 6.704 87(e^{-09})

3.6 Trend Analysis – OES CV6.

The plots are very scattered. There is a mild increasing tendency at a decreasing rate.

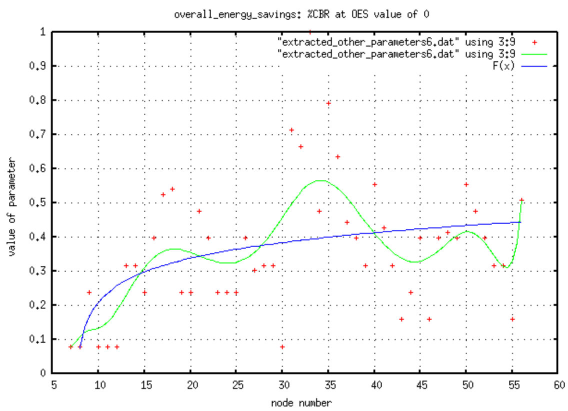

Figure 6: OES Critical Value 6

The potentially applicable equations are:

1. $F(x) = a * \log(b*(x + c)) + d$

Ch_sq = 0.032 342 4 F(80) = 0.475 864 760

F(100) = 0.494 936 501 F(120) = 0.510 257 941

2. $F(x) = a *x^{-0.25} * \log(b*(x+c)) + d$

Ch_sq = 0.029 530 9 F(80) = 0.140 108 284

F(100) = -0.035 814 579 F(120) = -0.207 996 127

3. $F(x) = a *x^{-0.5} * \log(b*(x+c)) + d$

Ch_sq = 0.030 866 9 F(80) = 0.365 214 804

F(100) = 0.338 130 077 F(120) = 0.313 691 085

4. $F(x) = a * \log(b*(x+c)) + (d*x^{0.25})$

Ch_sq = 0.029 487 5 F(80) = 0.078 662 802

F(100) = -0.167 399 177 F(120) = -0.425 243 828

5. $F(x) = a*\log(b*(x+c))+ (d*x^{0.25})$

Ch_sq = 0.032 471 8 F(80) = 0.469 605 640

F(100) = 0.487 130 509 F(120) = 0.501 248 314

Choice of best fit for OES Critical Value 6

The equation in part 1 above has been selected even if the reduced ch_sq is not smallest, it has good extendability over larger node numbers. The parameters obtained for best fit are: a = 0.078 226 , b= 0.216 538 , c= -7.560 63 , d= 0.260 527

3.7 Trend Analysis – OES CV7.

The curve obtained here is mostly decreasing at a decreasing rate.

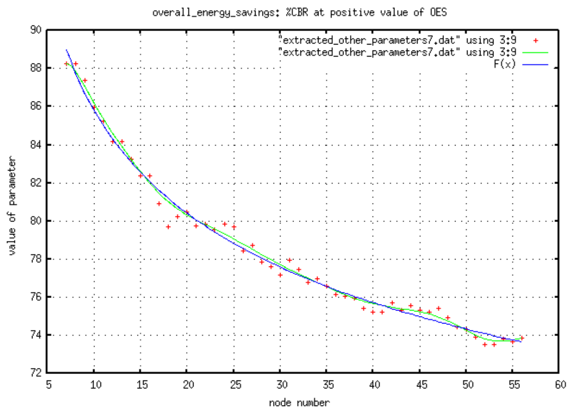

Figure 7: OES Critical Value 7

The potentially applicable equations are:

1. $F(x) = a * \exp(b* (x + c)) + d$

Ch_sq = 0.275 267 F(80) = 73.217 928 627

F(100) = 73.015 054 317 F(120) = 72.945 424 302

2. $F(x) = a *x^{0.25} * \exp(b* (x+c)) + d$

Ch_sq = 0.353 84 F(80) = 73.733 835 636

F(100) = 73.650 798 860 F(120) = 73.631 184 984

3. $F(x) = a *x^{-0.25} * \exp(b* (x+c)) + d$

Ch_sq = 0.208 006 F(80) = 71.561 819 162

F(100) = 70.312 027 150 F(120) = 69.313 363 986

4. $F(x) = a *x^{-0.5} * \exp(b* (x+c)) + d$

Ch_sq = 0.273 844 F(80) = 72.496 891 646

F(100) = 71.694 909 545 F(120) = 71.128 441 851

Choice of best fit for OES Critical Value 7

The equation in part 3 above has been selected because of smallest reduced chi-square value obtained and good extendability. The parameters obtained for best fit are:

a = 59.710 3, b= -0.000 650 687, c= 12.612 4, d= 52.764 1

3.8 Trend Analysis – OES CV8.

The plots here are very scattered but overall, a decreasing linear tendency is observed.

$F(x) = d *x + f$

International Journal of Advance in Computer Science & its application – IJCSIA 2018
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Volume 7 : Issue 2 [ISSN : 2250-3765] - Publication Date: 25 June , 2018

Ch_sq = 0.046 656 1 F(80) = 2.064 002 674
F(100) = 1.947 457 162 F(120) = 1.830 911 650

The parameters of fit are: d=-0.005 827 28, f= 2.530 18
A tolerance of ±0.2 is suggested here.

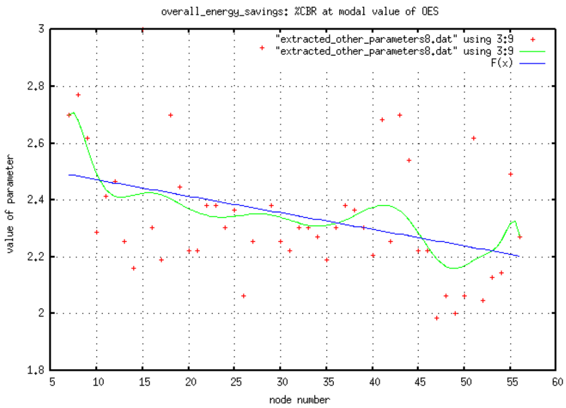

Figure 8: OES Critical Value 8

3.9 Trend Analysis – OES CV9.

Though the plots are very scattered, a very mildly increasing linear tendency is observed.

F(x)= d *x + f
Ch_sq = 64.295 7 F(80) = 69.004 150 840
F(100) = 69.260 955 073 F(120) = 69.517 759 305

The parameters of fit are: d=0.012 840 2 , f= 67.976 9
A tolerance of ±10 is suggested. The projected values vary between 68 and 71 for up to very large node numbers (around 200)

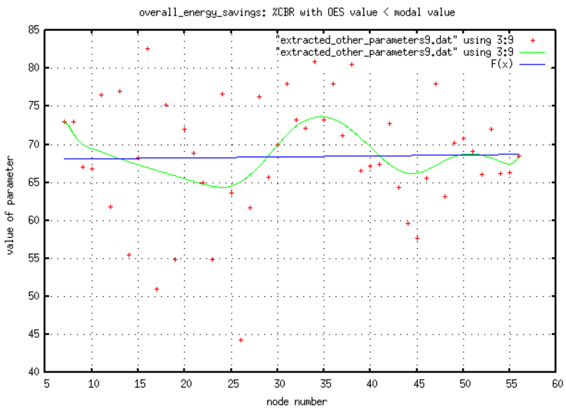

Figure 9: OES Critical Value 9

3.10 Trend Analysis – OES CV10.

The curve appears to start decreasing at a decreasing rate until a minimum point is reached and then the curve starts increasing.

The potentially applicable equations are:

1. F(x)= a * x * exp (b* (x + c)) + d
   Ch_sq = 178.664 F(80) = -194.927 203 006
   F(100)=-151.512 380 973 F(120)=-110.122 782 342
2. F(x)= a *x^2 * exp (b* (x + c)) + d
   Ch_sq = 179.214 F(80) = -169.255 920 371
   F(100)=-122.859 922 390 F(120) = -90.438 029 622
3. F(x)= a *x^f * exp (b* (x + c)) + d
   Ch_sq = 178.269 F(80)= -181.835 365 125
   F(100)= -135.304 569 361 F(120)= -96.742 935 277

Choice of best fit for OES Critical Value 10

The equation in part 3 above has been selected because of smallest reduced chi-square value obtained and good extendability. The parameters obtained for best fit are:

a = -4.070 85 , b= -0.032 515 , c= 1.268 11 , d= -14.843 7 , f=1.450 6

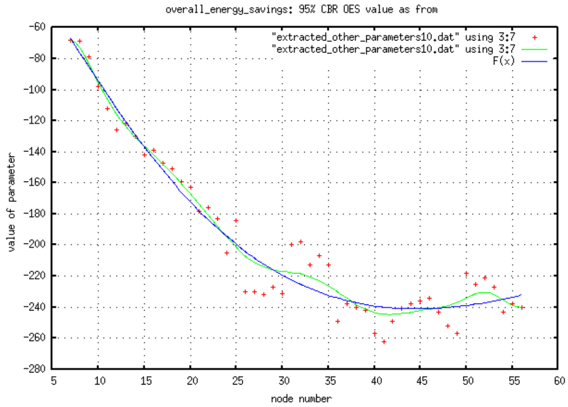

Figure 10: OES Critical Value 10

3.11 Trend Analysis – OES CV11.

Generally, the curve is increasing at a decreasing rate

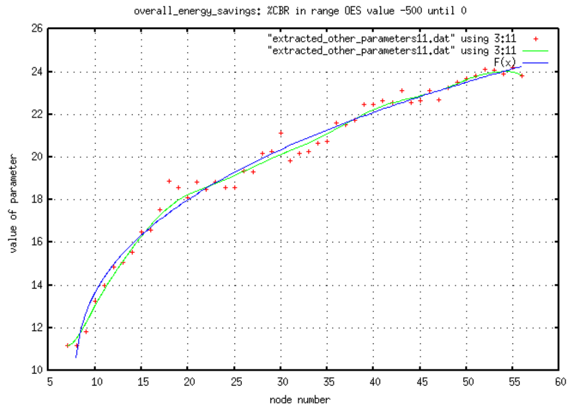

Figure 11: OES Critical Value 11

The potentially applicable equations are:

1. F(x)= a * log (b* (x + c)) + d
   Ch_sq = 0.238 574 F(80) = 26.119 749 704
   F(100) = 27.373 027 788 F(120) = 28.391 669 641
2. F(x)= a * $x^{0.5}$ * log (b* (x+c)) + d
   Ch_sq = 0.271 233 F(80) = 27.302 091 445
   F(100) = 29.285 947 469 F(120) = 31.036 674 030
3. F(x)= a * $x^{0.2}$ * log (b* (x+c)) + d
   Ch_sq = 0.220 172 F(80) = 26.724 775 625
   F(100) = 28.376 359 605 F(120) = 29.793 119 525

4. $F(x) = a * x^{0.15} * \log(b*(x+c)) + d$

Ch_sq = 0.240 706 F(80) = 26.301 210 226

F(100) = 27.771 408 090 F(120) = 29.016 300 584

Choice of best fit for OES Critical Value 11

The equation in part 3 above has been selected because of smallest reduced chi-square value obtained and good extendability. The parameters obtained for best fit are:

a = 0.966 355 , b= 304.692 , c= -7.574 , d= 3.506 19

4. Conclusion.

This piece of research was aimed at and has fulfilled the identification of some critical values related to metric OES and their corresponding trends over varying node densities in a MANET topography of 300 x 300 m^2. The models put forward have involved quite complicated mathematical equations and will assist in studying MANETs for MAUC environment from a software engineering perspective. These mathematical models may be mapped onto programming algorithms, to generate more realistic simulation scenarios for testing newly developed communication protocols and middleware for ubicomp. The experiment was carried out in NS-2 over Linux. The plottings and "fit" attempts were done in gnuplot. For two critical values, best fit was evaluated with flat values and for remaining nine critical values, least reduced chi-square and best extendability of equations at higher node numbers have been used.

Assumptions stated in prior papers [15, 31] hold here also. Gnuplot is also assumed as suitable for this study. The intrinsic constructs of gnuplot is not criticised here.

This work is a follow-up of previous papers [1-13, 15, 31] and dwells as prone to further enhancements. One such further work identified is formulating a method of predictability for metric OES and its trend.

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