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Trend Analyses of Critical Values Obtained for Packets Per Distance Achievable in Ubicomp MANETs Using Location-Aware Transmission Strategies.

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Abstract **– The fields of location-tracking, ubicomp functionalities and MANET transmission strategies are subject to intense research [1-57]. Their merging is also subject to lots of attention. In particular, the enforcement of location-aware transmission strategies is prone to enhance energy management in ubicomp. Amongst the enhancements awaited [1] are: the application of land-based GPS systems, improved location refresh rates and accuracy, development of better protocols optimised for transmission according to distance criteria and refining the precision of the distance criteria to apply the protocol. The knowledge of distance coverages by transmitted packets in ubicomp and corresponding variations over different node densities, is definitely useful for refining transmission protocols in MANETs. Such an empirical study was made previously [26] whereby the metric Packets Per Distance, PPD, was devised and studied. This was followed by another study [42] in which the trends of parameters of equations for metric PPD were studied.**

In this paper, the next level of scrutiny is set as: "What are the observable critical values in PPD trends? What are the trends of variation observable within each critical value for metric PPD over varying node densities?" Designers may use the results presented here, towards formulation of better "realistic" ubicomp scenarios for future ubicomp tools.

This piece of research remains a follow-up of previous ones [1-57].

Key terms: Ubicomp- Ubiquitous Computing, MAUC-Mobile and Ubiquitous Computing, PPD- Packets Per Distance, CBR- Constant Bit Rate, MANET- Mobile Adhoc Network, CV- Critical Value.

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1. Introduction

Future ubicomp topographies, especially outdoor ones, may be deficiently equipped with networking devices. Different topographies may demonstrate quite a lot of heterogeneity concerning accuracy level of distance measurement, location refresh rates and performance level of existing protocols. MANETs remain the hopeful solution to these problems. Performance of MANETs may be enhanced with location-aware transmission. Various ways of studying the resulting Packet Per Distance coverages in ubicomp for most optimal protocol performances exist. One such method was introduced previously [26], in which the behaviour of the metric PPD was depicted as split into two:

- Previous to peak values, linear tendency is visible:
  `F(x) = d * x + f`
- As from the peak value onwards, the exponentially trend is visible:
  `G(x) = a * exp (b * (x-c))`

A follow-up study [42] was carried out to model mathematically the five parameters of equations observed above. Results obtained will definitively be useful towards better understanding the evolution and predictability of ubicomp environments. These progresses are still laggardly occurring and will facilitate designers towards producing more realistic simulation scenarios based on which more precise test cases can be executed over experimental components for middleware and communication protocols.

The probing now required for metric PPD is the identification of observable critical values obtained during experiments execution and formulation of corresponding theoretical trend of such CVs over varying node densities. Nine such CVs were observed.

The key contribution of this paper is the mathematical derivation of the trends of variations for each of the nine CVs observed for metric PPD explained previously [26, 42] over node numbers ranging from 7 until 56. Such categories of information must necessarily be presented in a structured format so as to fluidly aid designers to understand the evolution and predictability of ubicomp behaviour and be well equipped to carry reliable simulation scenarios testing of new communication features. The rest of this paper is organised as follows: section 2- PPD Critical Values, section 3- Critical Values Trend Analyses- Metric PPD, section 4- Conclusion and References.

2. PPD Critical Values.

2.0 Critical Values Identified.

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Nine CVs were identified as follows: Column headings are: C1→PPD CV, C2→Meaning of PPD CV, C3→Corresponding figure number for PPD CV.

C1	C2	C3
1	Total number of packets in circulation.	1
2	% packets at 0 m.	2
3	Maximum distance packets travel.	3
4	% packets at maximum distance.	4
5	Modal value of distance packets travel.	5
6	% packets at modal value of distance.	6
7	% packets travelling < modal value of distance.	7
8	% packets travelling > modal value of distance.	8
9	% packets at smallest value < modal value of distance.	9

Table 1: PPD Critical Values

It is recalled that distance is measured to nearest meter.

2.1 Experimental Critical Values Obtained.

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

NN	CV1	CV2	CV3
7	422948945	0.981875957	359
8	487056531	14.310619110	359
9	546986573	12.805610678	359
10	629255705	11.594384353	363
11	689282046	10.566200646	363
12	748222616	9.774288753	363
13	810253860	9.061030947	363
14	871331869	8.446644800	363
15	931865741	7.896057851	363
16	990860926	7.413592067	363
17	1051546908	7.006759227	363
18	1110558045	6.630028149	363
19	1172929399	6.293126003	363
20	1231518084	5.984909029	363
21	1290949156	5.690049113	369
22	1348988525	5.441308183	369
23	1408740211	5.211895453	389
24	1468131004	5.001651678	389
25	1529967229	4.788994928	389
26	1589501936	4.506808100	381
27	1649854293	4.351390866	381
28	1711459977	4.205352329	388
29	1771297512	4.070953327	388
30	1829957752	3.942102593	389
31	1886553606	3.815415728	389
32	1944424833	3.702106699	389
33	2005951676	3.599531826	389
34	2066155746	3.500180668	389
35	2125598932	3.404899669	389
36	2188663557	3.317068664	389
37	2246187164	3.191755796	389
38	2303891929	3.104357592	389
39	2365628914	3.026256129	389
40	2427171632	2.949503820	389
41	2487197964	2.883629250	389
42	2543796380	2.822532478	389
43	2603692082	2.758803451	389
44	2660028705	2.701091453	389
45	2716735114	2.645611809	389
46	2778428023	2.586327931	389
47	2838831467	2.527322204	389
48	2900907987	2.476683829	389
49	2959346460	2.427038773	389
50	3023618060	2.389524357	368
51	3084282330	2.345783435	368
52	3141277599	2.306740386	368
53	3202570278	2.266356292	368
54	3262306837	2.228893621	368
55	3320546034	2.191417232	368
56	3380459625	2.152764064	368

Table 2(a): Experimental Critical Values Obtained(1)

NN	CV4	CV5	CV6
7	0.000225796	31	1.486884191
8	0.000196076	31	1.287047725
9	0.000174593	31	1.341119026
10	0.001591563	32	1.358053162
11	0.002944368	32	1.428853988
12	0.002455152	29	1.500569184
13	0.000821965	23	1.611943941
14	0.001011096	23	1.686025787
15	0.000632065	23	1.754024671
16	0.001161111	23	1.820796494
17	0.001008039	21	1.908077980
18	0.001128262	21	1.980098933
19	0.000861944	21	2.064416752
20	0.000052780	21	2.122171273
21	0.000002324	20	2.193066463
22	0.000002224	19	2.252648517
23	0.000262291	19	2.316725592
24	0.000240442	19	2.366216973
25	0.000235626	19	2.421309313
26	0.000041208	19	2.475408246
27	0.000027275	19	2.521171365
28	0.000001636	19	2.560655557
29	0.000001581	18	2.613029866
30	0.000034154	18	2.654058048
31	0.000128541	16	2.724988033
32	0.000059915	16	2.762038320
33	0.000062564	16	2.814523933
34	0.000060741	16	2.860438286
35	0.000012232	16	2.907832944
36	0.000011194	16	2.963590671
37	0.000031832	16	2.993781688
38	0.000044707	16	3.036857681
39	0.000041004	16	3.071178813
40	0.000036256	16	3.108190043
41	0.000023923	16	3.142586201
42	0.000054485	16	3.178529643
43	0.000019011	16	3.223753284
44	0.000015413	16	3.271821159
45	0.000030183	16	3.297024084

46	0.000022387	14	3.323815778
47	0.000021910	14	3.364481165
48	0.000039367	14	3.402162545
49	0.000047139	14	3.433064779
50	0.000041507	14	3.495962053
51	0.000044095	14	3.531660411
52	0.000043454	13	3.563593044
53	0.000038563	13	3.601462450
54	0.000030806	13	3.636982967
55	0.000029965	13	3.672141833
56	0.000032096	13	3.708147794

Table 2(b): Experimental Critical Values Obtained(2)

NN	CV7	CV8	CV9
7	24.939505405	73.573610403	0.103547723
8	35.044535518	63.668416757	0.089743997
9	36.092018295	62.566862679	0.091348495
10	41.204701036	57.437245801	0.394979335
11	42.590221043	55.980924970	0.400278089
12	39.503209831	58.996220986	0.395673017
13	31.767608858	66.620447202	0.424520779
14	32.552183398	65.761790815	0.425772445
15	33.432083217	64.813892112	0.417240256
16	34.299571825	63.879631681	0.404137543
17	31.484008605	66.607913415	0.393326343
18	32.343153212	65.676747855	0.390380586
19	33.213462237	64.722121011	0.386610055
20	34.124319526	63.753509201	0.386494040
21	33.030815584	64.776117953	0.386774954
22	31.567489501	66.179861982	0.386142425
23	32.229636128	65.453638279	0.385123102
24	32.977795965	64.655987062	0.387162044
25	33.583386968	63.995303719	0.387384899
26	34.433058596	63.091533158	0.388714028
27	35.062366807	62.416461828	0.390629708
28	35.692767006	61.746577437	0.391423176
29	33.765588782	63.621381353	0.396489238
30	34.366073605	62.979868346	0.397100916
31	29.698780529	67.576231438	0.393249149
32	30.174391781	67.063569898	0.398176616
33	30.773853597	66.411622470	0.402132220
34	31.291341723	65.848219992	0.406607489
35	31.871070398	65.221096658	0.412663785
36	32.440252351	64.596156978	0.416755694
37	33.027181345	63.979036967	0.422846731
38	33.621601571	63.341540748	0.428413671
39	34.228084008	62.700737179	0.438074372
40	34.873003534	62.018806423	0.443854767
41	35.392554101	61.464859699	0.450651664
42	35.869842027	60.951628330	0.456348161
43	36.542150993	60.234095723	0.462840022
44	37.023658397	59.704520444	0.467972055
45	37.461802395	59.241173521	0.471052512
46	31.333338629	65.342845594	0.476229540
47	31.817519656	64.817999180	0.483648331
48	32.227219105	64.370618350	0.489521800
49	32.616508342	63.950426879	0.495629363
50	33.205882922	63.298155026	0.509864430
51	33.590305009	62.878034580	0.513783866
52	30.423828518	66.012578438	0.521119496
53	30.841224993	65.557312557	0.528190938
54	31.183804738	65.179212295	0.534227553
55	31.542650946	64.785207221	0.541115462
56	31.951312922	64.340539284	0.551490687

Table 2(c): Experimental Critical Values Obtained(3)

3. Critical Values Trend Analyses- Metric PPD.

3.0 General Procedure Adopted.

The initial logical step is to plot the tabulated data for each PPD CV on gnuplot. The step that must follow is the graphical analyses and relating the general observations obtainable. As third step, different equations of fits are experimented. Choice of best fit is made based values of least reduced chi-square and best extendability produced at node numbers 80, 100 and 120 for eight CVs; and for one CV, it is based on flat values. The conclusive step is documenting the related parameter values for each PPD CV equation.

3.1 Trend Analysis – PPD CV1.

The number of packets in circulation tends to increase very linearly with number of nodes.

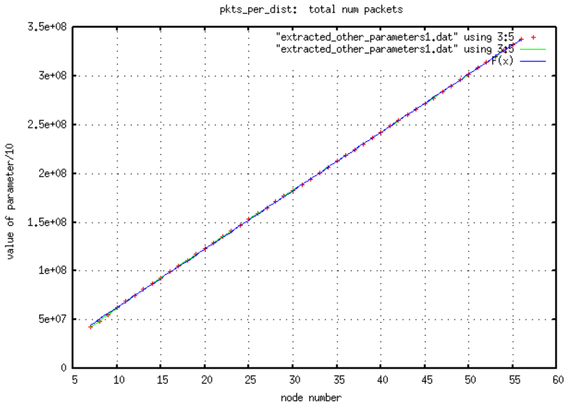

Figure 1: PPD Critical Value 1

The applicable equation of trend has been

```
F(x) = (d * x + f ) * 10
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Ch_sq = 4.196 38(e^{11}) F(80) = 4 821 197 343.513 67

F(100) = 6 019 565 585.977 04 F(120) = 7 217 933 828.440 41

The parameters obtained for best fit are: d = 5.991 84(e^{+06}) , f = 2.772 44(e^{+06})

Ch_sq is not 0 despite appearance of very clean linear tendency. This is because the y-values on the y-axis are very large and have a large range. The vertical distance from plots to the line are very well existent but are not visible on graphical display.

3.2 Trend Analysis – PPD CV2.

The first plot at node number 7 appears as an outlier: it is hence ignored for fitting equation. Else, the plots show a decreasing trend at a decreasing rate.

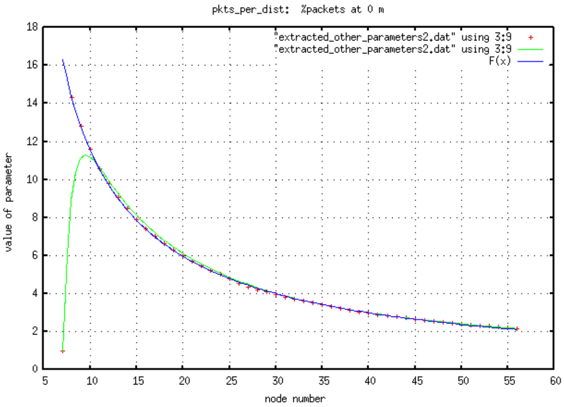

Figure 2: PPD Critical Value 2

The potentially applicable equations are:

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

   Ch_sq = 0.003 556 62 F(80) = 1.284 692 863

   F(100)= 0.893 812 946 F(120)= 0.615 902 522

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

   Ch_sq = 0.001 463 68 F(80) = 1.410 337 958

   F(100)= 1.081 443 152 F(120)= 0.857 716 052

Choice of best fit for PPD Critical Value 2

The equation in part 2 above has been selected because of smallest reduced chi-square value obtained and good extendability. The parameters for best fit are:

a= -0.019 095 3, b = 50.426 3, c = -45.77, d= -0.427 347

3.3 Trend Analysis – PPD CV3.

Instead of a consistent curve of tendency, four distinct levels of max_distance_packets travel are noted:

Level	Node	Y-axis
1	7-9	359
2	10-22	363
3	23-49	389
4	50-56	368

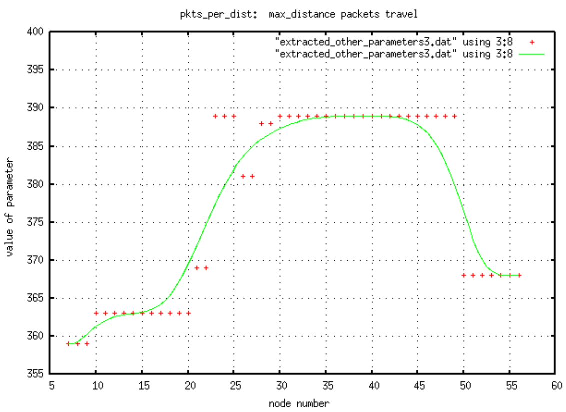

Figure 3: PPD Critical Value 3

Range of node numbers for levels 1 until 3 depict an increasing value. It can be suggested that level 4 will hold for node number around 50-90.

3.4 Trend Analysis – PPD CV4.

Here, certain initial sudden upward bursts are noted but the plots are mostly stabilising at very low values.

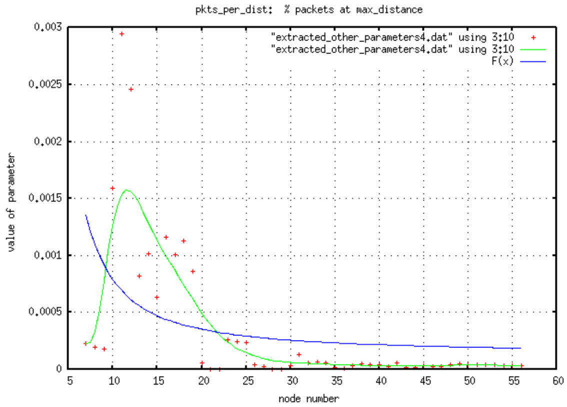

Figure 4: PPD Critical Value 4

The potentially applicable equations are:

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

   Ch_sq = 2.655 04(e^{-07}) F(80) = -0.000 138 193

   F(100)= -0.000 198 911 F(120)= -0.000 244 319

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

   Ch_sq = 2.762 97(e^{-07}) F(80) = -8.95………

   F(100) = -3. ………… F(120) = -4.85........

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

   Ch_sq = 3.156 8(e^{-07}) F(80) = 0.000 163 944

   F(100)= 0.000 153 617 F(120)= 0.000 146 457

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

   Ch_sq = 2.307 92(e^{-07}) F(80) = -0.000 559

   F(100)= -0.000 733 348 F(120)= -0.000 866 367

Choice of best fit for PPD Critical Value 4

The equation in part 3 above has been selected because of good extendability over larger node numbers even if ch_sq is not least. The parameters obtained for best fit are: a = 0.000 684 885 , b= 0.048 965 2

3.5 Trend Analysis – PPD CV5.

Here, some staircase features are noted but overall is a decreasing curve at a decreasing rate.

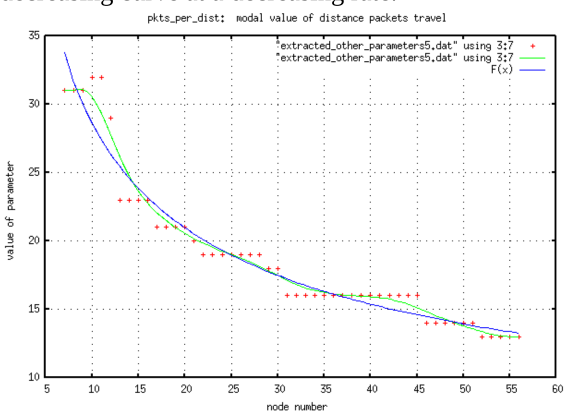

Figure 5: PPD Critical Value 5

The potentially applicable equations are:

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

   Ch_sq = 1.656 49 F(80) = 11.307 736 257

   F(100)= 10.252 269 005 F(120)= 9.466 508 066

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

Ch_sq = 1.711 79 F(80) = 11.704 860 354
F(100)= 10.810 789 776 F(120)= 10.170 303 629

3. $F(x) = (f*x^{-1}) * \exp((b*x^{a})+c) + d$
Ch_sq = 1.693 48 F(80) = 11.326 135 786
F(100)= 10.276 584 195 F(120)= 9.495 603 665

4. $F(x) = (f*x^{-2}) * \exp((b*x^{a})+c) + d$
Ch_sq = 1.698 34 F(80)= 11.384 389 394
F(100)= 10.349 407 290 F(120)= 9.579 216 930

Choice of best fit for PPD Critical Value 5

The equation in part 3 above has been selected because of good extendability over larger node numbers even if ch_sq is not least. The parameters obtained for best fit are: a = 0.010 558 5 , b= 49.846 1 , c = -46.501 7 , d = 0.296 785 , f = 2.938 22

3.6 Trend Analysis – PPD CV6.

The curve obtained here is generally increasing at a decreasing rate.

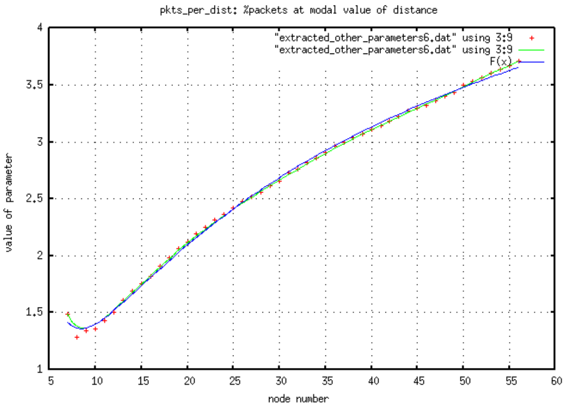

Figure 6: PPD Critical Value 6

The potentially applicable equations are:

1. $F(x) = (a/x^{0.5}) * \log(b*(x-c)) + d$
Ch_sq = 0.000 856 076 F(80) = 4.196 112 369
F(100)= 4.521 891 051 F(120)= 4.779 101 964

2. $F(x) = (a*x^{f}) * \log(b*(x-c)) + d$
Ch_sq = 0.002 086 45 F(80) = 4.414 093 057
F(100)= 4.890 246 564 F(120)= 5.298 307 187

Choice of best fit for PPD Critical Value 6

The equation in part 1 above has been selected because of least ch_sq and good extendability over larger node numbers. The parameters obtained for best fit are:
a = -8.932 94 , b= 1.934 51 , c = 1.799 34 , d= 9.208 89

3.7 Trend Analysis – PPD CV7.

The plots are quite scattered. Different straight line trends are visible for different ranges. Overall, the decreasing linear trend applies best with possibility of tolerance limit of ±4.

The applicable equation is: $F(x) = d * x + f$

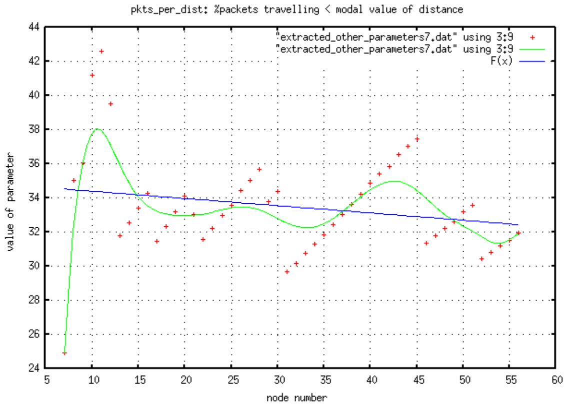

Figure 7: PPD Critical Value 7

Ch_sq = 8.244 83 F(80) = 31.424 242 282
F(100)= 30.573 845 488 F(120)= 29.723 448 693
Parameters for best fit: d = -0.042 519 8 , f = 34.825 8

3.8 Trend Analysis – PPD CV8.

Nearly same observations as in critical value 7 are made here also. A very mildly decreasing linear tendency seems to apply with tolerance limits.

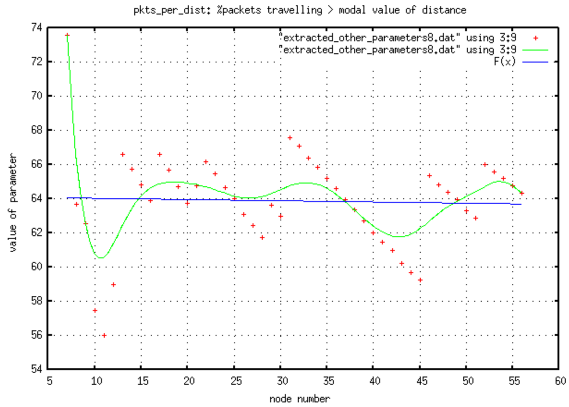

Figure 8: PPD Critical Value 8

The applicable equation is: $F(x) = d * x + f$
Ch_sq = 8.052 68 F(80) = 63.526 228 566
F(100)= 63.381 479 176 F(120)= 63.236 729 786
Parameters for best fit: d = -0.007 237 47 , f = 64.105 2
A tolerance limit of ±3.5 is suggested here.

3.9 Trend Analysis – PPD CV9.

The curve obtained here depicts rapid initial increase reaching a peak, then decreases reaching a minimum point and continues increasing at a moderately increasing rate.

The potentially applicable equations are:

1. $F(x)=h/((a*(x-g)^{2})+b)/(\exp((c*(x-g))+d)+f)$
Ch_sq = 0.001 099 05 F(80) = 1.179 379 672
F(100)= 2.472 680 445 F(120)= 5.646 313 040

2. $F(x)=h/((a*(x-g)^{2})+b)/(\exp((c*(x-g))+d)+(f/x))$
Ch_sq = 0.001 242 97 F(80) = 1.173 660 133
F(100)= 2.452 859 198 F(120)= 5.561 602 609

3. $F(x)=h/((a*(x-g)^{2})+b)/(\exp((c*(x-g))+d) + (f/x^{2}))$

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Ch_sq = 0.001 284 57 F(80) = 1.146 142 641

F(100)= 2.346 248 710 F(120)= 5.200 410 920

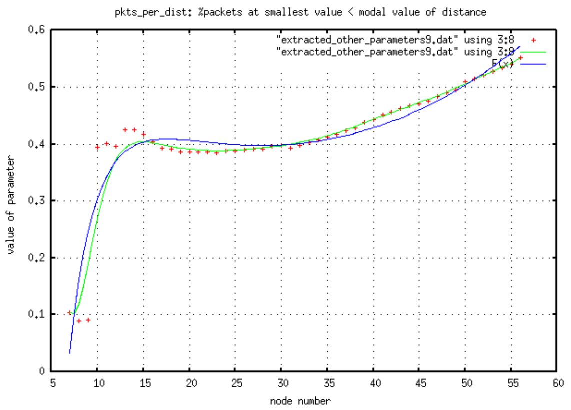

Figure 9: PPD Critical Value 9

Choice of best fit for PPD Critical Value 9

The equation in part 3 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 = 0.380 727 , b= 69.152 5 , c= 0.058 014 3 , d= -0.227 62 , f = -49.801 6 , g = 1.611 81, h = 36.718 9

4. Conclusion.

This study had as aim the determination of the relevant CVs observable for metric PPD and analyse their corresponding trends over varying node densities in a MANET topography of 300 x 300m^2. The models portrayed in this paper, are framed with mathematical equations of quite complex levels. The output detailed here will add to the amount of existing tools for more detailed MANETs studies for ubicomp environments viewed from software engineering notions. These output can subtly be implemented into computational methods to develop better simulation scenarios which will then serve for enabling better testing procedures over communication and middleware components.

This experiment was performed in NS-2 over Linux. Plottings and "Fit" attempts were done with gnuplot software. Determination of best fit was done using least reduced chi-square and best extendability at higher node numbers for eight CVs and flat value for one CV. Assumptions stated previously [26, 42] are maintained.

This study is positioned as a follow-up to previous studies [1-57]. Upgrades to these results remain possible in the future. One such task is the formulation of predictability for metric PPD and its trend.

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