**For discussion at Joint PAP2/802.24 meeting on March 19, 2013**

This submission for PAP2 is to provide a response to IEEE 802.24 SG TAG questions regarding the applicability of the Framework SG Modeling Tool to Mesh networks

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**Note from IEEE 802.24 SG TAG via Bruce Kraemer**

The 802.24 working group, in charge of reviewing and promoting 802 standards of interest for Smart Grid applications and interoperability reviewed the SGIP PAP02 network model tool identified as [Frmwrk-Tool-Dtls-r0.7.xls](http://collaborate.nist.gov/twiki-sggrid/pub/SmartGrid/PAP02Wireless/Frmwrk-Tool-Dtls-r0.7.xls).

The group concluded that the model is well adapted and valuable for the types of network topologies it describes, which is assumes an asymmetrical base-station to subscriber network structure, like those supported by 802.16 and Cellular technology.

The group also concluded that such model is not appropriate to the modeling of Point to Point (or Peer to Peer) applications or Mesh topologies.

The limitation for Point to Point applications is due to the fact that the modeling tool assumes base station to subscriber station architecture.

In the case of Mesh technologies the driving component in the sizing of the network is not range but rather connectivity among nodes, which is not represented in the model. Additionally, Mesh networks in most cases use frequency agility techniques which further complicates the problem as devices within a NAN would hop orthogonally on channels within the same spectrum thus making estimations on link bandwidth and throughput within such NAN virtually impossible to calculate. Also the typical location of nodes for the NAN mesh topology is that of the electricity meter, outside the premises and 4-5 feet above ground level, and the SGIP PAP02 model is currently not able to represent a symmetrical network of peers (equivalent nodes), in a heavily cluttered environment,  with multiple potential communication paths between those nodes.

**Response:**

The propagation projections performed by the modeling tool are based on five traditional path loss models derived for terrestrial-based PMP topologies. The conditions for which these PL models are considered valid represent the limitations of the modeling tool insofar as estimating the coverage area. These path loss models generally assume a **base station antenna height above roof-tops or in the case of the Erceg-SUI model at 10 meters or above and the ITU M.2135-1 Urban Micro-cell which is valid for a 10 meter antenna height in a Manhattan-like high rise environment**. Additionally they generally assume a client device at an antenna height at 10 meters or less.

Key inputs for the range estimation are system gain, which is technology specific, and the link budget which includes values for fade margin, penetration loss, and interference margin. The penetration loss assumes a ‘worse’ case scenario in that the least favorable location for an end-point is selected and applied to all end-points in the coverage area even though some end-points may be in locations that are more propagation-friendly.

The fade margin is determined by user-selected values for and **‘cell-edge performance’** and **‘availability’**. There is also an entry for **‘alternative paths’.** This feature in the tool is to account for BS to BS handover for end-points at the cell edge which, in the event of a fade on one link, would switch over to another BS within its range. Typically, end-points at the cell edge would have roughly equal probability of connecting to 2 or 3 different base stations in a multi-cellular network. By selecting a number for alternate paths greater than 1, the tool adjusts the entered value for the required availability to account for the number of alternative paths. This reduces the required fade margin which increases the link budget resulting in extended range and coverage.

The tool also has an entry to adjust the **‘system gain’** up or down by a few dB to assess the sensitivity to link budget changes.

To estimate channel capacity the tool uses an estimated SNR vs. MCS. The ‘peak’ UL and DL modulation is specific to the technology being studied (based on reported peak rates). The tool accommodates UL and DL peak modulation efficiencies corresponding to QPSK, 16QAM, 32QAM, 64QAM, or 256QAM based on the entries for technology-specific peak UL and DL spectral efficiency. The minimum modulation is determined by the required cell-edge performance and the channel BW.

The latency model described in Section 5.4.7 was added to the tool to assess latency performance. The latency requirement and payload sizes come from the SG framework numbers (framework sheets in the tool). There is a means to enter a value for the number of **‘serial links’** the payload must traverse for e2e connectivity. The tool divides the latency requirement by the number of links and adds additional latency OH to account for the added node processing.

**Can the tool be used to model a Mesh network?**

To simulate a Mesh network it would be necessary to have propagation path information for end-point to end-point links with low antenna heights, including multi-hops scenarios, and indoor and outdoor end-point locations. Models do exist for analyzing Mesh networks but generally require 3-D imaging data and predetermined end-point locations. I have not had personal experience in using any of these models, but I expect them to be computationally intensive and probably best suited to smaller well-defined specific geographical areas of interest for pre-deployment RF planning. I also do not know how or if latency is taken into account with these models.

Although the SG modeling tool, as currently configured, is not intended to simulate a Mesh network it may be possible, with the assumption that all the end-point locations are outdoors, to approximate some of the attributes of a Mesh network with the existing modeling tool using three of the entries described above, namely:

* Variation in ‘System Gain’
* Number of ‘Alternate Paths’
* Number of ‘Serial Links’

For suburban, rural, and low density rural region FANs or NANs, the outdoor end-point assumption is a reasonable expectation.

These entries can be used as follows:

1. A Mesh topology enables an end-point to act as a mini-BS and connect to another end-point or end-points. The model doesn’t analyze this on a link by link basis. However, this attribute, in effect, simply helps to extend the range beyond the coverage area of the ‘main’ BS or DAP. If we can agree on an expected value for the extended range, 10, 20, 30%, etc., this effect can be converted to an equivalent number of dB and added to the **‘System Gain’**.
2. In a Mesh network an end-point can look for an alternate path, via other end-points, back to the ‘main’ BS or DAP in the event of an equipment failure or a deep fade on its main path. This attribute can be simulated in the modeling tool by increasing the number **‘alternate paths’** beyond 2 or 3, the values more appropriate for BS to BS handover. This further reduces the necessary fade margin leading to increased range and coverage.
3. A negative attribute of the Mesh network is the additional latency introduced by added node processing for message traversing multiple hops. This can be simulated by adding additional **‘serial links’.** The model thenapportions thelatency requirement on a per link basis.

Using the SG model in this manner to estimate the coverage for a Mesh network may not be precise but may be adequate for roughly assessing the benefits of a Mesh topology over a PMP topology. Some of the limitations would be:

* The exact number of end-points directly connected to the BS or DAP would not be known since some end-points will be connected via other end-points. The total number of ‘messages’ however will still be valid number, so from a latency perspective (message payload queuing), this may not matter.
* Further inaccuracy with channel capacity estimation: This estimate in the model is based on a uniform distribution of end-points which may already be an inaccurate assumption, particularly for rural areas.

**Re: Point-to-Point links:**

There are numerous and well-proven models available for PtP analysis, Egli and Longly-Rice models are two examples. These are referenced in NISTIR 7761 v2 Section 5. Some PtP models use GIS data and account for diffraction loss over rough terrain, buildings, etc. Fresnel Zone clearances, earth curvature, etc are also taken into account.

**Assessment for wireless solutions in the ISM bands with Mesh topology**

**ISM bands in U.S.:**

* 902-928 MHz (801.11ah) (also 802.15.4 not submitted)
* 2400-2483.5 MHz (802.11n) (also 802.15.4 not submitted)
* 5725-5835 MHz (802.11ac and WiGRID)

**EIRP Limitations:** Per CFR Part 90, EIRP is limited to +36 dBm (4 Watts) in the ISM bands. This compares to +75 dBm in the licensed bands just above and below the 2400 MHz ISM band and a range of. +43 to +85 dBm for licensed bands between 700 and 6000 MHz.

ISM example at 2450 MHz for Suburban area with Terrain Type A with BS/DAP antenna height at 10 meters and outdoor end-point/smart meter locations.

|  | **PMP Topology** | **Simulated Mesh** | **PMP w/o EIRP Limit** |
| --- | --- | --- | --- |
| BS EIRP | +36 dBm | +36 dBm | +55.4 dBm |
| EP EIRP | +27 dBm | +27 dBm | +27 dBm |
| Alternate Paths | 3 | 6 | 3 |
| Serial Paths | 1 | 5 | 1 |
| Min UL/DL System Gain | DL: 153.4 dB | DL: 156.4 dB | UL:160.7 dB |
| Link Budget | 142.3 dB | 148.4 dB | 149.6 dB |
| Base Stations | 81 R | 50 R | 45 R |
| End-Points/BS | 1371 | 2221 | 2468 |
| Latency | L = -/0.12 sec | L = 0.25/0.02 secLOH > L | L = -/0.12 sec |

The following table assumes a **PMP topology for the three ISM bands with a +36 dBm maximum EIRP.** Rural and Low Density Rural assume 2 and 3 serial links respectively.

BS antenna height is 25 meters for Rural and 30 meters for Low Density Rural. It is 10 meters for other locations. Meter or end-point locations are ID Basement for Dense Urban, Indoor Bus for Urban and Outdoor for other venues. Latency OH = 100 ms for 1 link, 125 ms for 2 links, and 150 ms for 3 links.

| **ISM Bands****Highload** | **Dense Urban** | **Urban** | **Suburban****Type A** | **Rural****Type A** | **Low Density Rural****Type A** |
| --- | --- | --- | --- | --- | --- |
| **Coverage Area** | **5 mi2** | **20 mi2** | **100 mi2** | **1000 mi2** | **3000 mi2** |
| 802.11ah 920 MHz* TDD
* BW=5 MHz
* Pkt=1500
 | No valid path loss model | BS = 33 REP = 2039L = -/0.12SGL=1.53% | BS = 309 LEP = 360L = -/0.12BS = 46 CBS = 37 R | BS = 169 REP = 384L=0.15/0.06LOH > L | BS = 441 REP = 25L=0.2/0.04 LOH > L |
| 802.11n 2450 MHz* TDD
* BW=5 MHz
* Pkt=1500
 | Range< 60 meters | BS = 133 REP = 519L = -/0/12SGL<0.1% | BS = 81 REP = 1371L = -/0.12SGL=6.63% | BS = 684 REP = 95L=0.15/0.06LOH > L | BS = 1796EP = 7L=0.2/0.04LOH > L |
| 801.11ac 5800 MHz* TDD
* BW=5 MHz
* Pkt=1500
 | Range< 20 meters | BS = 980 REP = 71L = -/0.12SGL<0.1% | BS = 263 REP = 423L = -/0.12SGL = 1.0% | BS =1646 REP = 40L=0.15/0.06LOH > LSGL<0.1% | BS=4306 REP = 3L= 0.2/0.04LOH > LSGL<0.1% |
| WiGRID 5800 MHz* A-TDD
* BW=5 MHz
* Pkt=14400
 | Range< 20 meters | BS = 980 REP = 71L = -/1.10SGL<0.1% | BS = 263 REP = 423L = -/1.10SGL=1.52% | BS =1646 REP = 40L = -/0.55SGL<0.1% | BS=4306 REP = 40L = -/0.35SGL<0.1% |

Based on PMP topology 2450 and 5800 MHz ISM would not be economical for Dense Urban FAN or NAN with Indoor basement-located end-points due to high penetration loss. This doesn’t rule out Dense Urban applications such as: DAP backhaul, Aggregation for indoor meter bands with PtP indoor to outdoor relay, etc.

The table can be re-run with other parameters for Suburban, Rural, and Low Density Rural to simulate mesh, if we can agree on the suitability of the model and values for the parameters.