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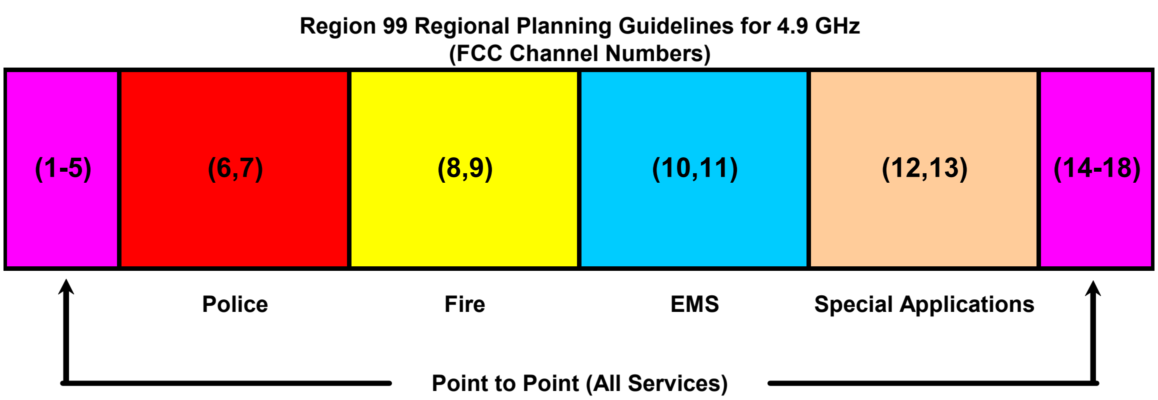
Overview of Incident Scenario

The following scenario illustrates an example of an operational deployment of 4.9 GHz at the scene of a severe incident. This scenario demonstrates many important characteristics of 4.9 GHz utilization, including its role as a support resource for public safety, how multiple frequency band resources (including 4.9 GHz) work together to meet public safety's operational objectives, what types of applications 4.9 GHz will be used for, the physical limitations and propagations characteristics of the 4.9 GHz band, and how technology is used to solve some of the propagation constraints inherent to the use of 4.9 GHz.

In this scenario, even though multiple agencies have high density deployments of 4.9 GHz units at the scene, only a minimum degree of incident spectrum management is assumed (or even required). Most all infrastructure resources serving the area have been destroyed, so all communications are set up "on-the-fly". It is assumed that all 4.9 GHz channels have been assigned to individual services or operations ahead of time through the local Regional Planning Guidelines (fictitious and only for illustrative purposes, see Figure 1). For this scenario, incident managers do not consider adjacent channel planning at all.

Figure 1: The Local Regional Planning Guidelines for Incident 4.9 GHz Utilization



What should be clear after the reader navigates this scenario and reviews the simulation results is that the standard technologies used to support the first responder operations can support this extremely complex and stressing incident without any noticeable degradation of Quality of Service (QoS) to the end users at the scene. Furthermore, it will be apparent that the selection of a standard emission mask (e.g. DSRC Mask A or IEEE 802.11a/j) over a more stringent mask (e.g. DSRC Mask C) has little if any effect upon real life user operations.

Incident Scenario

The FCC has asked NPSTC for further clarification, and more detailed modeling of the effects that the different emissions masks have upon real life operational scenarios. In order to demonstrate the operational effects of 4.9 GHz Mask selection on public safety operations, a very complex scenario was developed. This scenario was loosely based upon a scenario presented[1] in the SAFECOM *Statement of Requirements for Public Safety Wireless Communications and Interoperability*[2], but certain factors have been modified to make this example particularly stressing in terms of operational spectrum management. As requested by the Wireless Bureau of the FCC, several elements were incorporated in the modified scenario presented here.

- Operational examples of typical public safety applications.
- Operational examples of "*Mission Critical*[3]" public safety applications.
- Operational examples "Worst Case" incident management practices, such as locating tactical Access Points (AP's) in close proximity, and not managing or considering adjacent channel interference effects at all.
- Detailed propagation modeling or real life situations, with worst case effects.
- Detailed assessment of packet data transfer effects and packet collisions.

The public safety communications incident unfolds as follows.

01:15 PM

An explosion rocks the edge of a downtown area (see Figure 2 and Figure 3) in a mid-size US town. The blast emanates from a small car loaded with explosives parked near a popular restaurant. Immediate casualties from the sidewalk café result and dozens of additional people inside the restaurant are wounded from the glass and flying debris. Portions of the building start to ignite due to the blast and heat. Emergency alarms are set off, and multiple 911 calls are received at the local Public Safety Answering Point (PSAP).

Within minutes, the two primary public safety radio sites serving the area are destroyed by related terrorist acts. These additional attacks leave the area with no infrastructure-based voice and narrowband data coverage.

01:18 - 01:25 PM

[1] Appendix C.5 Scenario: Terrorist Car Bomb

[2] The SAFECOM Program, Department of Homeland Security, Version 1.0, March 10, 2004.

[3] Here "Mission Critical" is defined an application that is intolerant to excess communications latency (or coverage loss), with such latency/loss resulting in immediate loss of life and/or property.

Police, Fire and EMS units arrive on the scene, immediately work to cordon off and evacuate the area, perform rescue and fire fighting efforts, and start to set up a triage area for the wounded. With no infrastructure communications to rely on, they immediately turn to the 700 MHz Tactical Incident Command Structure (TICS) that they have all trained to utilize for interoperability between the first responder services.

01:25 PM

Additional Police, Fire, and EMS command units arrive on the scene and set up tactical fire ground communications. With no infrastructure to rely on, all units immediately go to their assigned 700 MHz narrowband channels for tactical and command unit voice communications at the scene. Voice interoperability between the services is still handled by TICS protocols using the 700 MHz channel assignments that were put in place beforehand. All external communications to and from the scene are handled via temporary 4.9 GHz point-to-point links[4] between each services' Mobile Command Centers (MCCs) and a public safety Metropolitan Area Network (MAN).

Data communications for all of the Police, Fire and EMS services at the scene is provided by 4.9 GHz mobile access points (APs)[5] that are located on each of the MCCs. These mobile commend centers are parked in close proximity to each other to facilitate coordination between the Fire Ground commanders of each of the services. All services turn their 4.9 GHz radios at the scene, scan the access points for their respective services, and commence communications. The only spectrum management role of each of the incident commanders is to direct that the 4.9 GHz access points are set to transmit on the channels recommended by the local regional planning committee to avoid co-channel interference at the scene (see Figure 1). Adjacent channel interference effects are ***not*** considered by the incident commanders.

01:30 PM

Within 15 minutes of the explosion, full tactical voice (700 MHz) and Data (4.9 GHz) communications capabilities are available at the scene. A full perimeter is in place, and the area on the south side of the incident is widened to encompass some chemical storage tanks that may present further targets, or present a hazard to on-scene personnel.

Because of propagation effects, 700 MHz voice coverage of the scene is fairly reliable and available over approximately 95% of the incident response area. However, many units are not able to achieve data coverage at 4.9 GHz due to large areas of the scene having no clear propagation path to the mobile AP's. The incident commanders enable mesh routing in all units across the on scene so that data communications (albeit with reduced throughput) are available to all units. See the example communications routing diagrams in Figure 5 through Figure 8. These show how the data may be routed through various intermediate communications nodes.

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[4] These links are pre-assigned throughout the Region by the regional plan, are shared by all public safety services, and reside on the outer 5 MHz channels of the 4.9 GHz allocation. See Figure 1.

[5] These are based upon IEEE 802.11j technology using the standard "A" transmitter mask.

01:33 PM

Fire units on the scene have identified a briefcase that was left in a trash can on the south side of the building hit by the explosion. Fearing that this represents a secondary device that is intended to target first responders, it is decided to deploy a remote controlled bomb squad robot that is on scene. The remote controlled robot operates on a single 4.9 GHz channel that is reserved for such emergencies. The bomb squad incident commander first issues an "all-clear" signal over the channel beacon to clear any accidental operations on this reserve channel, and then initiates the robot's operations utilizing a directional antenna pointed at the robot. Other than operating on this reserve channel (which is adjacent to the EMS on scene operating channel) with a directional antenna, standard 802.11 OFDM transceivers are employed for both the robot and its control point.

01:33 – 3:00 PM

All first responders perform their duties. On-scene data applications that are utilized in order to support incident response operations are as follows:

Police (35 Active Mobile Data Units on Scene)

- From AP/Incident Command to Units
    - PDA-based applications that include text messaging and the display of on-scene maps that show the geo-location of all other police units [estimated worst case physical layer throughput requirement of approximately 1,000 KB/hour/unit].

- From Perimeter Units to AP/Incident Command
    - Photographs of crowds and individuals in the vicinity of the perimeter. These are sent to Federal Government databases via the mobile command unit's back haul links for image recognition analyses against those known to be associated with terrorist activities [estimated worst case physical layer throughput requirement of approximately 6,000 KB/hour/unit, corresponding to six (6) high resolution JPEG images].
    - Geo-location Information [estimated worst case physical layer throughput requirement of approximately 500 KB/hour/unit].

Fire (13 Active Mobile Data Units on Scene)

- From AP/Incident Command to Units
    - Head up display-based applications that include text messaging, the display of on-scene maps that show the geo-location of all other fire units, and periodically updated infra-red (IR) imagery of affected buildings showing possible ignition/combustion activities [estimated worst case physical layer throughput requirement of approximately 5,000 KB/hour/unit].

- From Perimeter Units to AP/Incident Command
    - Tactical images and video on demand [estimated worst case physical layer throughput requirement of approximately 50,000 KB/hour/unit].
    - Geo-location Information [estimated worst case physical layer throughput requirement of approximately 500 KB/hour/unit].
    - Unit "health" status that included vital signs, oxygen supplies, and ambient temperature [estimated worst case physical layer throughput requirement of approximately 500 KB/hour/unit].

EMS (12 Active Mobile Data Units on Scene)

- From AP/Incident Command to Units
    - Head up display-based applications that include text messaging, and vital signs [estimated worst case physical layer throughput requirement of approximately 5,000 KB/hour/unit].
- From Perimeter Units to AP/Incident Command
    - Telemedicine images and video on demand [estimated worst case physical layer throughput requirement of approximately 50,000 KB/hour/unit]
    - Patient and triage "health" status that includes vital signs, medicinal and blood supplies [estimated worst case physical layer throughput requirement of approximately 5,000 KB/hour/unit].

Special Operations - Bomb Squad (1 Active Mobile Data Unit on Scene)

- From AP/Incident Command to Robot Unit
    - Control information [estimated worst case physical layer throughput requirement of approximately 50,000 KB/hour/unit].
- From Perimeter Units to AP/Incident Command
    - Video Information for robot control [estimated worst case physical layer throughput requirement of approximately 225,000 KB/hour/unit, corresponding to full-cycle use of a 500 kbps compressed video feed].

A summary of the User Application requirements is shown in Table 1.

Table 1: User Application PHY Throughput Requirements

	User Application PHY Throughput Requirements (MB/Hr/Unit)	
Service	**Inbound**	**Outbound**
Police	1.0	10.5
Fire	5.0	51.0
EMS	5.0	55.0
Bomb Squad Robot	50.0	225.0

Technical parameters of the 4.9 GHz wireless devices are as follows:

- All access points and mobile (i.e. not backhaul) devices operate at on 10 MHz channels, utilizing standard IEEE 802.11 OFDM technologies (NOTE, both Mask A and mask C were considered, although Mask C is *not* a COTS implementation of this standard)
- All mobile (i.e. not backhaul) devices operate at transmitter power levels of 20 dBm
- Antennas gains minus line losses are: 0 dBi (mobile units), 6 dBi (APs), and 12 dBi (Bomb Squad Robot Links)
- Antenna heights are 1.5 m for mobile devices, 4 meters for incident command center access points.

03:00

The fire has been extinguished, and all of the wounded have been moved to area hospitals. Casualties have been transported to the County morgue. The secondary device that was identified was indeed found to be explosive, but it has been disabled and disposed of by the bomb squad robot. All units on scene switch to their secondary roles which include forensic activities and perimeter control. City works and other services move in for clean up, and vehicle traffic control and rerouting.

Figure 2: Incident Scene before Explosion

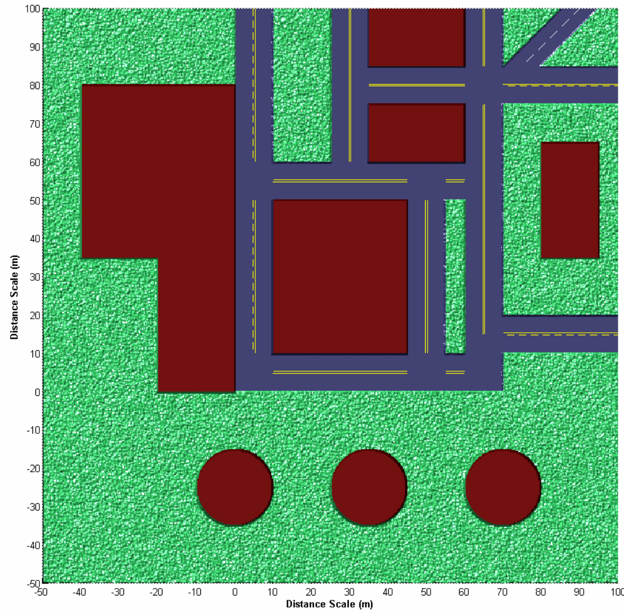


Figure 3: Incident Scene before Explosion

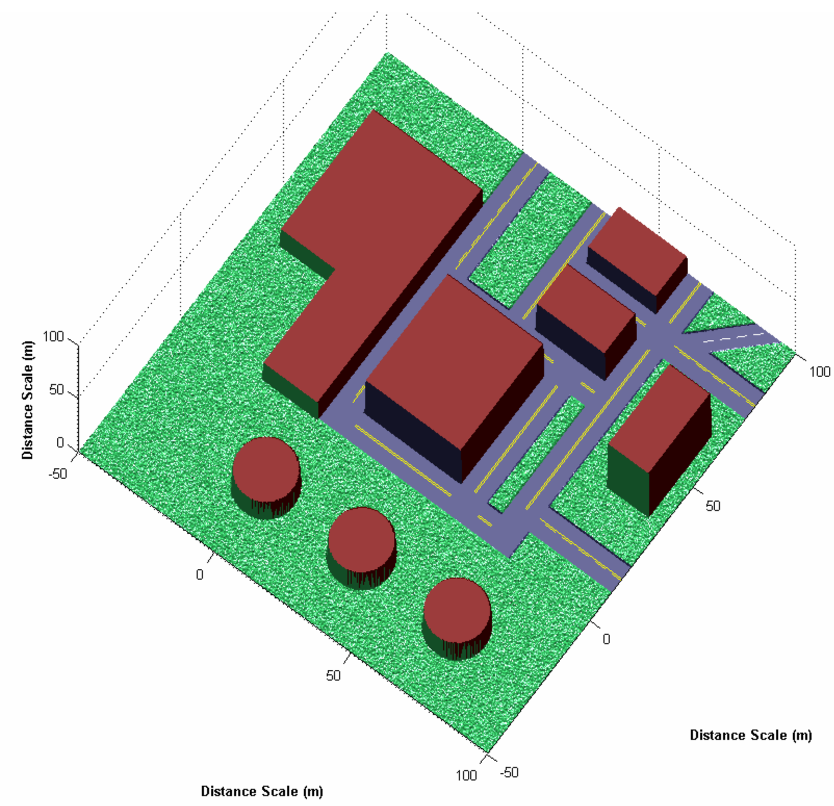


Figure 4: Incident Scene after Explosion - Public Safety On-Scene

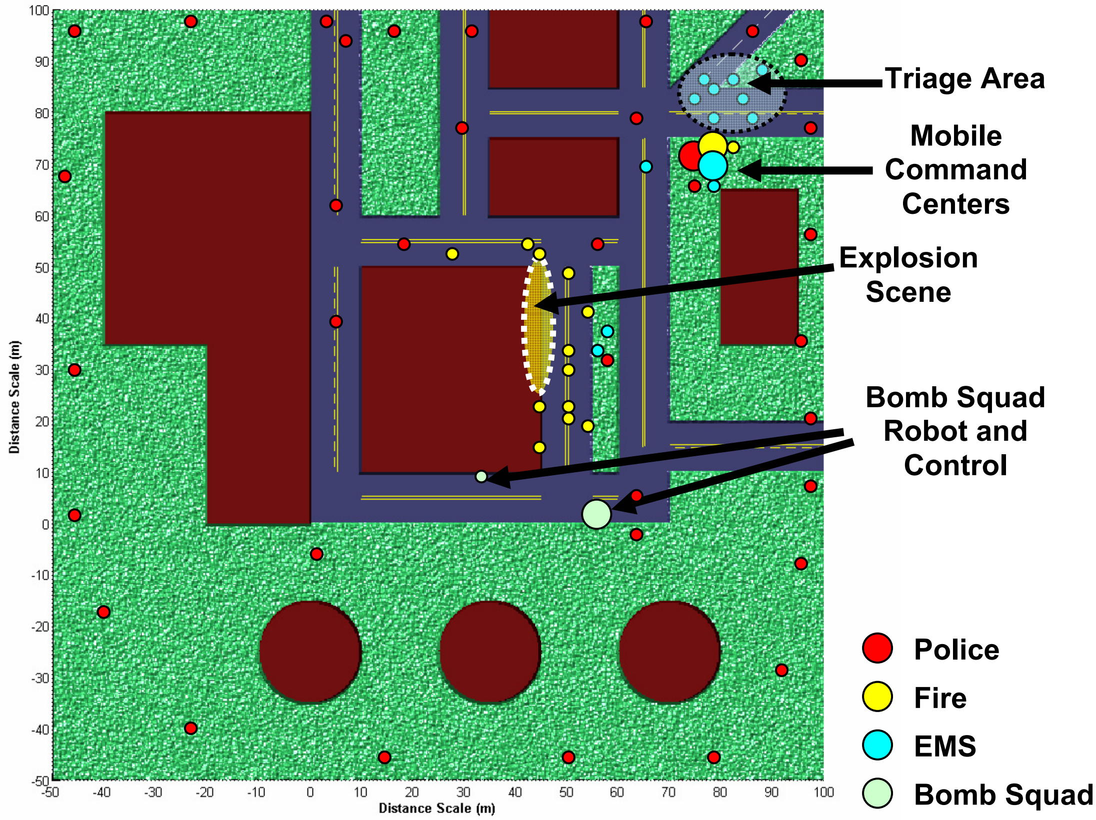


Figure 5: Example of On Scene Data Communications and Routing – Police Services

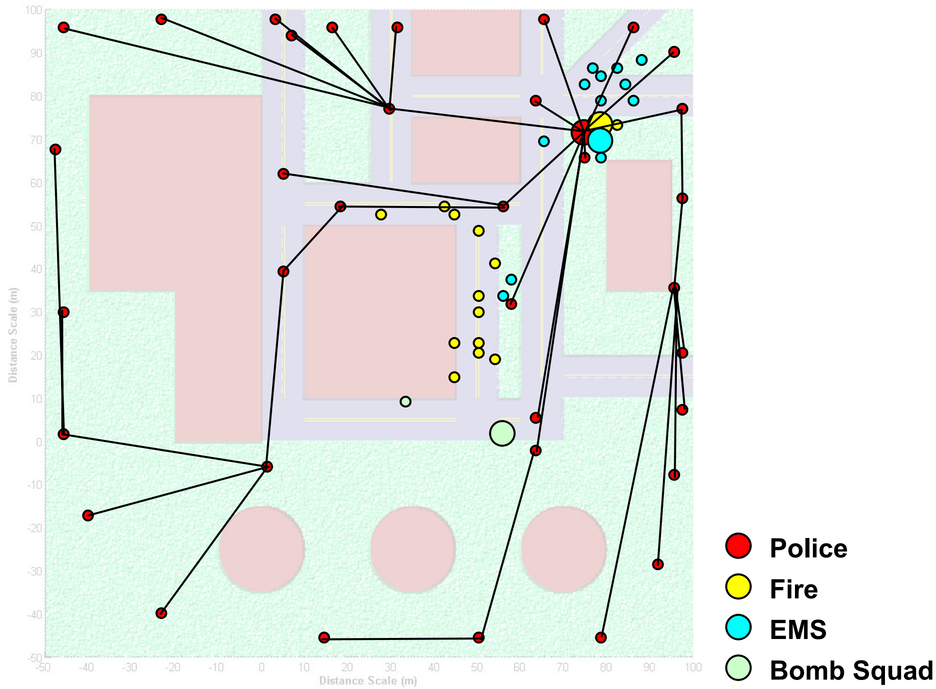


Figure 6: Example of On Scene Data Communications and Routing – Fire Services

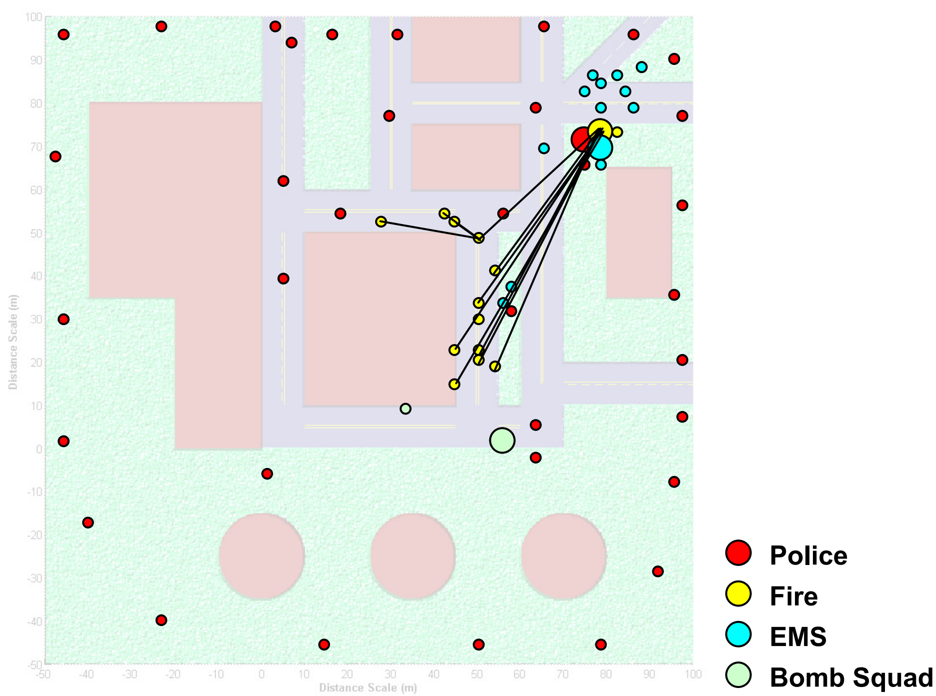


Figure 7: Example of On Scene Data Communications and Routing – EMS Services

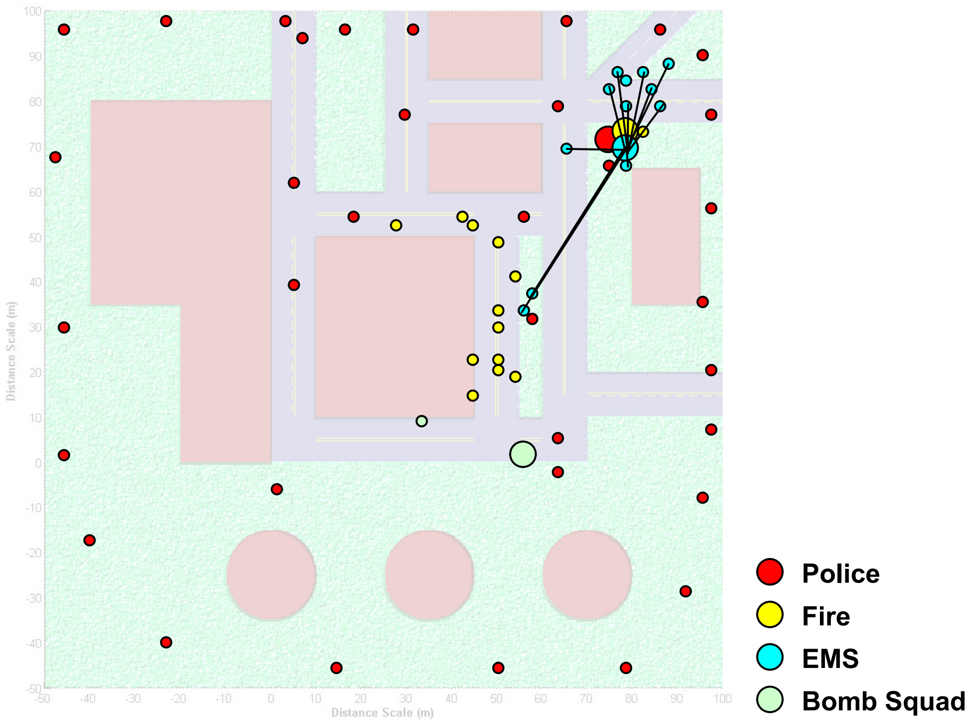
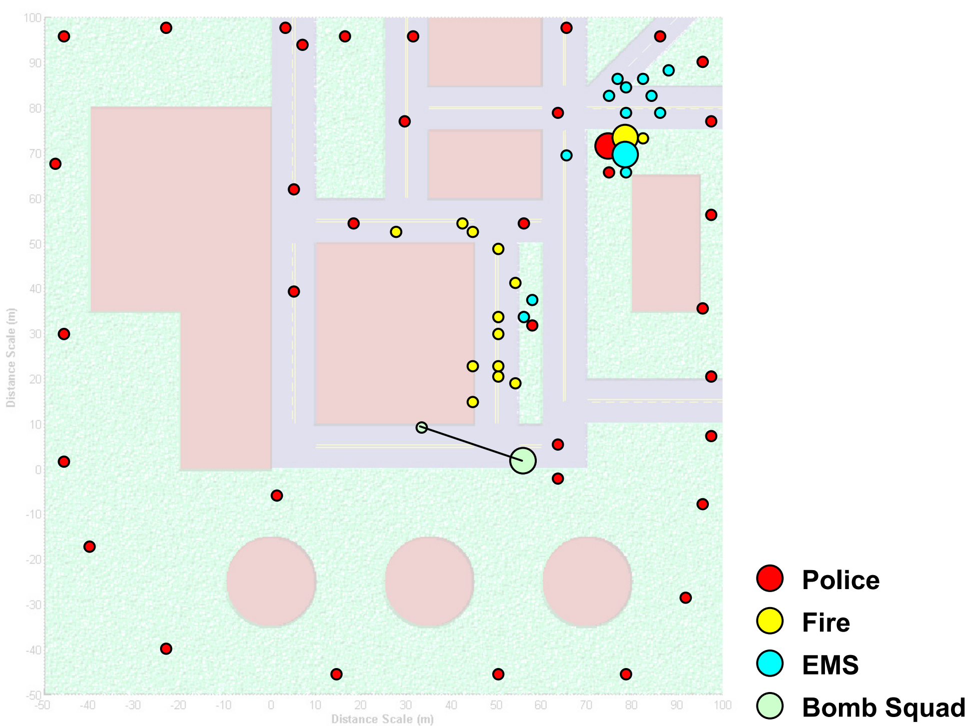


Figure 8: Example of On Scene Data Communications and Routing – Bomb Squad



Analyses of Data Communications Performance

Detailed analyses of the 4.9 GHz Radio Frequency (RF) environment and packet distributions at the incident scene were undertaken in order to assess the impacts of Mask selection on public safety operations during this stressing scenario. These are documented and described in Appendix A: 4.9 GHz Radio Propagation Models, Appendix B: PHY Data Rate Modeling Methodology, and Appendix C: Routing, Packet Distribution and Collisions. In this section, we will look at the high level effects, as seen from the perspective of the end users and incident managers.

Table 2 presents the overall results of the RF and Packet Collision simulations. The 1st column of this table indicates the communications node that is referred to in each corresponding row of the table, with additional information regarding each node is presented in the 6th column. Note that some nodes represent AP's, others mobile terminals, and others acting as both a mobile terminal and a routing point of other mobile terminals (akin to a mobile AP). The 2nd and 3rd columns denote the total PHY payload delivered from (i.e. transmitted at) each node and delivered to (i.e. received at) each node respectively, with all incident scene 4.9 GHz wireless devices operating on 10 MHz 802.11 OFDM-based technologies with the standard emissions mask (also commonly referred to as the DSRC-A mask). The 4th and 5th columns contain similar information, except that all incident scene 4.9 GHz wireless devices operate on 10 MHz 802.11 OFDM-based technologies with a more stringent standard emissions mask, corresponding to as the DSRC-C mask. Column 7 refers to the % difference between the average of the Mask A and Mask C simulations. Finally, the 8th column indicates whether the use of Mask A had any impact on end user applications during the duration of the incident.

What should strike the reader is that the use of Mask A as opposed to Mask C only affords an average data throughput increase of 5.8 %; and in fact many user nodes do not realize any throughput increase whatsoever. Furthermore, as is clearly seen in Table 3, even though the data rates at some nodes may be very slightly reduced using Mask A as opposed to Mask C, the throughput available far exceeds the throughput required. It is seen in this scenario that ***only 4% to 28% of each channel's capacity is required in order to support the user applications – even in this very stressing scenario***.

For additional reference, the average data rates for each channel achieved over the course of the incident are presented in

Table 4. Note that these data rates include the channel sense losses, with payload transfers occurring only 60% of the time on these "fully –loaded" channels[6]. These results are consistent with the other results obtained.

[6] See *Appendix C: Routing, Packet Distribution and Collisions* for further clarification of the "fully-loaded" channel concept.

Table 2: Simulation Results – Delivered Payload (over 90-minutes) and Mask Selection Effects

	MASK A		MASK C				
NODE	Data Transmitted (MB)	Data Received (MB)	Data Transmitted (MB)	Data Received (MB)	Comments	% Difference in Total Data Transfer	Does the use of Mask A have any Effect on User Application?
1	1,904.18	1,272.19	1,923.00	1,540.63	Police AP at Command Point	8.3%	No
2	748.37	822.51	832.94	863.94	Police Mobile and Mesh Router	7.4%	No
3	59.29	77.46	73.13	77.44	Police Mobile	9.2%	No
4	65.14	85.39	78.00	85.38	Police Mobile	7.9%	No
5	65.48	80.33	76.56	80.31	Police Mobile	7.1%	No
6	66.43	77.79	76.75	77.81	Police Mobile	6.7%	No
7	80.40	79.14	82.69	79.13	Police Mobile	1.4%	No
8	84.21	87.41	84.19	87.44	Police Mobile	0.0%	No
9	82.01	81.68	82.00	81.69	Police Mobile	0.0%	No
10	1,433.48	1,599.96	1,515.06	1,606.31	Police Mobile and Mesh Router	2.8%	No
11	12.26	27.77	15.50	36.63	Police Mobile	23.2%	No
12	16.67	36.60	23.81	36.75	Police Mobile	12.0%	No
13	84.71	87.41	84.69	87.44	Police Mobile	0.0%	No
14	1,249.26	1,243.01	1,249.25	1,243.00	Police Mobile and Mesh Router	0.0%	No
15	84.71	81.84	84.69	81.88	Police Mobile	0.0%	No
16	748.74	756.68	748.75	756.69	Police Mobile and Mesh Router	0.0%	No
17	81.68	81.51	81.69	81.50	Police Mobile	0.0%	No
18	82.01	84.04	82.00	84.06	Police Mobile	0.0%	No
19	415.13	420.02	415.13	420.00	Police Mobile and Mesh Router	0.0%	No
20	84.04	80.49	84.06	80.50	Police Mobile	0.0%	No
21	85.73	82.86	85.75	82.88	Police Mobile	0.0%	No
22	53.83	78.47	59.81	78.44	Police Mobile	4.3%	No
23	50.96	84.32	60.69	84.69	Police Mobile	6.9%	No
24	26.18	32.85	32.19	35.94	Police Mobile	13.4%	No
25	71.31	84.88	82.44	84.88	Police Mobile	6.6%	No
26	69.83	81.68	81.19	81.69	Police Mobile	7.0%	No
27	71.34	85.56	82.19	85.56	Police Mobile	6.5%	No
28	56.33	83.98	61.13	84.56	Police Mobile	3.7%	No
29	54.53	84.71	58.13	84.69	Police Mobile	2.5%	No
30	81.84	84.04	81.88	84.06	Police Mobile	0.0%	No
31	167.06	248.06	167.06	248.06	Police Mobile and Mesh Router	0.0%	No
32	81.17	85.39	81.19	85.38	Police Mobile	0.0%	No
33	83.36	79.05	83.38	79.63	Police Mobile	0.4%	No
34	67.05	80.23	80.75	81.31	Police Mobile	9.1%	No
35	61.50	85.31	68.88	86.75	Police Mobile	5.7%	No
36	79.63	85.22	81.69	85.25	Police Mobile	1.3%	No
37	4,388.25	2,301.44	4,449.94	3,146.06	Fire AP at Command Point	11.9%	No
38	323.56	341.25	341.38	341.38	Fire Mobile	2.6%	No
39	340.38	339.19	340.56	339.19	Fire Mobile	0.0%	No
40	348.19	338.00	348.44	338.00	Fire Mobile	0.0%	No
41	351.00	340.19	351.00	340.19	Fire Mobile	0.0%	No
42	1,740.94	2,394.75	2,064.25	2,404.00	Fire Mobile and Mesh Router	7.4%	No
43	183.44	346.19	253.31	349.31	Fire Mobile	12.1%	No
44	179.38	310.69	245.69	339.19	Fire Mobile	16.2%	No
45	161.94	335.06	226.50	345.13	Fire Mobile	13.1%	No
46	149.13	336.94	213.44	340.56	Fire Mobile	12.3%	No
47	138.50	341.06	196.31	342.25	Fire Mobile	11.0%	No
48	164.88	339.06	229.56	339.50	Fire Mobile	11.4%	No
49	148.81	337.81	207.31	342.25	Fire Mobile	11.5%	No
50	128.25	345.06	185.75	346.44	Fire Mobile	11.1%	No
51	5,422.50	4,387.31	5,441.85	5,205.39	EMS AP at Command Point	7.9%	No
52	377.56	449.06	442.09	449.04	EMS Mobile	7.2%	No
53	331.94	453.81	386.98	455.63	EMS Mobile	6.7%	No
54	346.25	429.81	389.42	447.36	EMS Mobile	7.3%	No
55	451.94	459.00	451.91	459.00	EMS Mobile	0.0%	No
56	379.50	462.88	457.82	462.88	EMS Mobile	8.5%	No
57	376.50	457.31	454.14	457.31	EMS Mobile	8.5%	No
58	365.69	453.06	442.61	453.09	EMS Mobile	8.6%	No
59	343.63	456.81	437.04	456.81	EMS Mobile	10.5%	No
60	360.75	456.81	443.83	456.81	EMS Mobile	9.2%	No
61	359.00	445.00	446.08	444.99	EMS Mobile	9.8%	No
62	360.94	454.25	440.19	454.28	EMS Mobile	8.9%	No
63	333.56	444.69	413.27	444.66	EMS Mobile	9.3%	No
64	999.88	9,970.09	1,002.88	9,970.09	Robot Control Point	0.0%	No
65	9,970.09	999.88	9,970.09	1,002.88	Robot	0.0%	No

Table 3: Simulation Results – Delivered Payload (Mask A) vs. Requirements

Service	User Application PHY Throughput Requirements (MB/Hr/Unit) Inbound	User Application PHY Throughput Requirements (MB/Hr/Unit) Outbound	Service	Minimum Provided by Mask A Technology (MB/Hr/Unit) Inbound	Minimum Provided by Mask A Technology (MB/Hr/Unit) Outbound	% of Channel Capacity Utliized by User Applications
Police	1.0	6.5	**Police**	18.5	8.2	**28%**
Fire	5.0	51.0	**Fire**	206.7	85.3	**19%**
EMS	5.0	55.0	**EMS**	286.0	220.6	**12%**
Bomb Squad Robot	50.0	225.0	**Bomb Squad Robot**	666.7	6,646.7	**4%**

Table 4: Simulation Results – Average Channel Data Rates over Incident Duration

Service (Channel)	Average Data Rate - Mask A (Mbps)	Average Data Rate - Mask C (Mbps)
Police (1)	12.76	13.25
Fire (2)	12.96	14.30
EMS (3)	14.53	15.77
Bomb Squad Robot (4)	16.25	16.26

Conclusions

What should be clear after the reader has navigated this scenario and reviewed the simulation results is that the standard technologies used to support the first responder operations can support this extremely complex and stressing incident without any noticeable degradation of Quality of Service (QoS) to the end users at the scene. Why can such technologies support this type of incident so well? One answer is that they were designed to; and designed well – with the significant resources of larger markets brought to bear to create technologies that perform well under completely uncontrolled environments. Another answer is that these technologies provide data rates far in excess of what most all public safety applications (even video) require – even under extreme conditions. In fact, in this very stressing scenario, only 4 to 28 % of the channel capacity resources are utilized by the user applications.

What should also be clear is that the emissions mask has little if any effect on the end users' or the incident managers' operations at the scene. Not only does significant capacity reserves exist over and above the user's needs (even with 65 simultaneous users operating continuously), but the RF and packet collision environment realities indicate that (even in this large scale event) there is no effect whatsoever on the operation of mission critical applications (e.g. the bomb squad robot links), with less than a 6% degradation in overall data rates due to adjacent channel effects – and with no incident spectrum management considerations given to circumvent this effect.

Again, to clearly reiterate, the selection and mandate of an emissions mask stricter than that represented by standard 802.11 OFDM technologies will only serve to <u>limit</u> the gains that would otherwise be afforded by market driven forces. It will <u>not</u> provide any significant performance gains, and will in fact <u>stifle the technological innovation</u> and <u>economic gains</u> that would be otherwise available by properly aligning public safety's requirements with technologies developed for larger markets.

Questions or Comment

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Appendix A: 4.9 GHz Radio Propagation Models

The FCC's public record on this proceeding included many techniques for modeling radio propagation effects at 4.9 GHz. For the most part however, only power law models such as free space (*n=2*), two ray reflection (*n=4*), and hybrid two slope models have been employed.

In this filing, NPSTC captures all of the important mechanisms that affect propagation at 4.9 GHz. The model used incorporates not only both free space spreading losses, but adds diffraction and reflection components so that real life performance can be captured. These effects are significant effects at 4.9 GHz, and in fact act as the primary propagation mechanism for many technologies at these higher frequencies. In reality, signal energy may be higher than free space conditions due to constructive reflections, signal energy may be blocked in cases where shadowing is present, and multipath reflections may provide signal energy even when no clear path between communications nodes exists. This is important, since *real life interference* often arises in cases where simple models could not possibly have predicted it. The models used herein are not simple.

The model used is an average of two separate and distinct models. The first is a modified Anderson-2D model[7] that uses knife edge diffraction for propagation impairments. The Anderson-2D model is a comprehensive, point-to-point, model for predicting field strength /path loss, and can be used from 30 MHz to 60 GHz scenarios. It is based upon free space losses, and incorporated the effects of diffraction and ground reflections. The second model is a full 3-D ray tracing model that captures the effect of multipath reflections from buildings at the scene. This model's component is clearly visible in Figure 9 and Figure 10, which show the modeled receive power from a single AP. In these figures, the reflections from objects at the incident scene create visible standing wave patterns due to the interaction of direct and reflective waves. Also note within these figures the effects of ground reflections, which give patters similar to those predicted by two-ray complex reflection coefficient models (e.g. Anderson 2-D). Note that both of these models allow for a signal to be at higher levels than free space would allow, due to the presence of constructive multipath reflections. This makes them ideal for looking at worst case interference scenarios.

[7] See the Telecommunications Industry Association's Technical Service Bulletin TSB-88A, "WIRELESS COMMUNICATIONS SYSTEMS – PERFORMANCE IN NOISE AND INTERFERENCE - LIMITED SITUATIONS RECOMMENDED METHODS FOR TECHNOLOGY INDEPENDENT MODELING, SIMULATION, AND VERIFICATION".

Figure 10 presents an especially useful glimpse at the propagations model results. In this figure, the incident layout is shown in the upper left; with the modeled receive power levels from a single AP shown in the upper right. Superimposed upon the modeled receive power levels in the upper right is two path "slices through the incident scene; with one vertical "slice", and one horizontal "slice". The lower portion of the figure presents the power levels over the length of these "slices", with samples every 25 cm (the modeled resolution). Although continuous, these clearly show the effects of multipath fading due to the modeled reflections at the incident scene. They also clearly show blocking and diffraction losses as the "slices" transition in and out of shadow regions.

Figure 11 and Figure 12 show the difference between the models utilized and that predicted by free space losses over the incident scene. These provide a view of where the models differ from free space losses, and illustrate the validity of the results. In Figure 11, the colormap scale on the right side of the figure shows the pass loss predicted by the model utilized, normalized by losses predicted by free space propagation. This figure clearly shows the symmetry around the free space spreading loss component of the models. Also note the additional losses in the blocked regions, and the fringe patterns due to multipath, indicative of the more complex capabilities of the models utilized. Figure 12 shows similar relationships, but within a two dimensional realm that offers the reader an alternative viewpoint of these relationships.

In summary, even though the analyses contained herein contains many conservative factors (conservative in the sense that interference effects are maximized), it clearly provides the most comprehensive and complex capture of 4.9 GHz propagation that exists on the record for this docket.

Figure 9: Example – Outbound Receive Power from One Mobile AP (dBm)

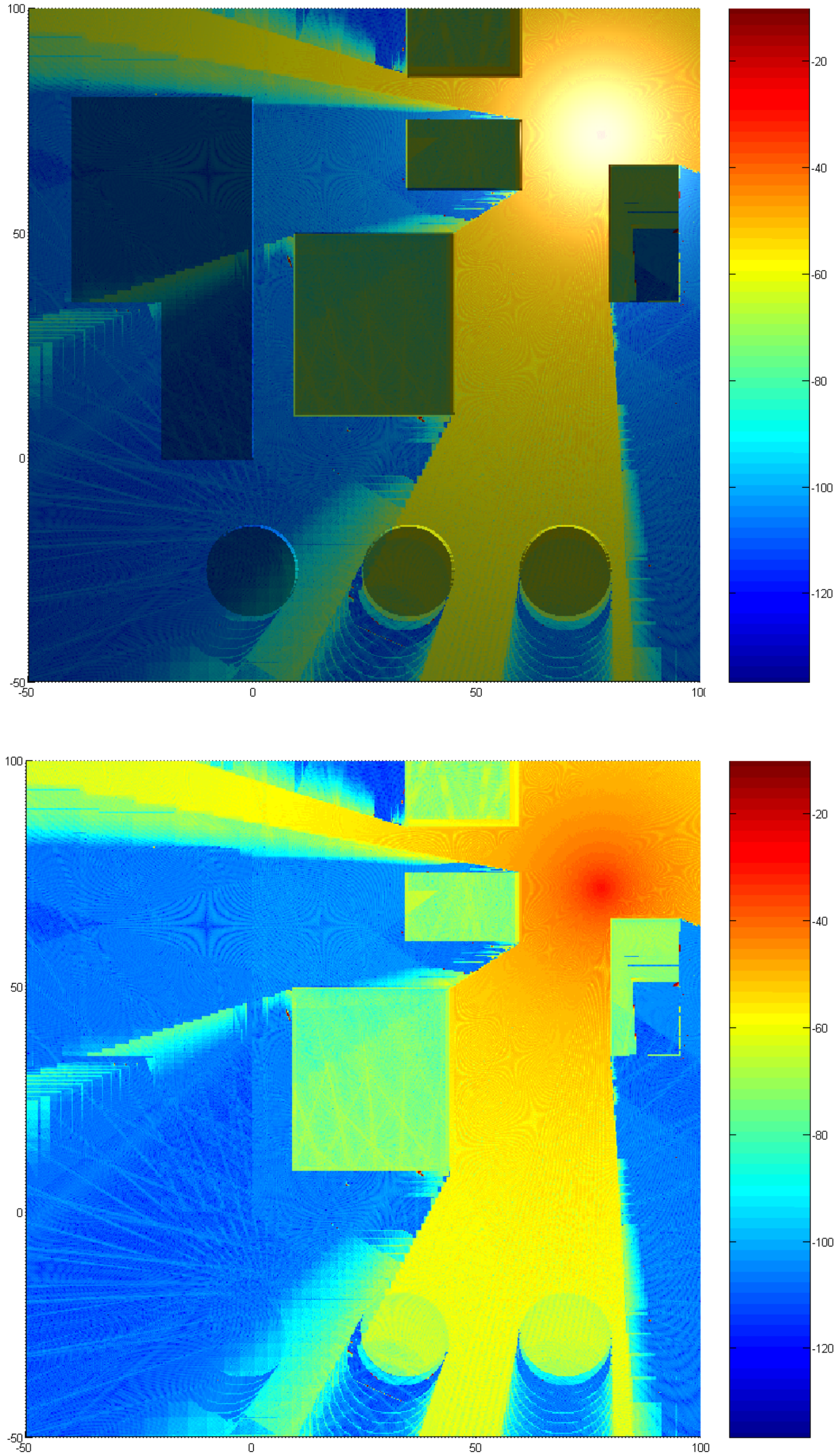


Figure 10: Incident Scene "Slices" Through Modeled Receiver Power Levels (Single AP)

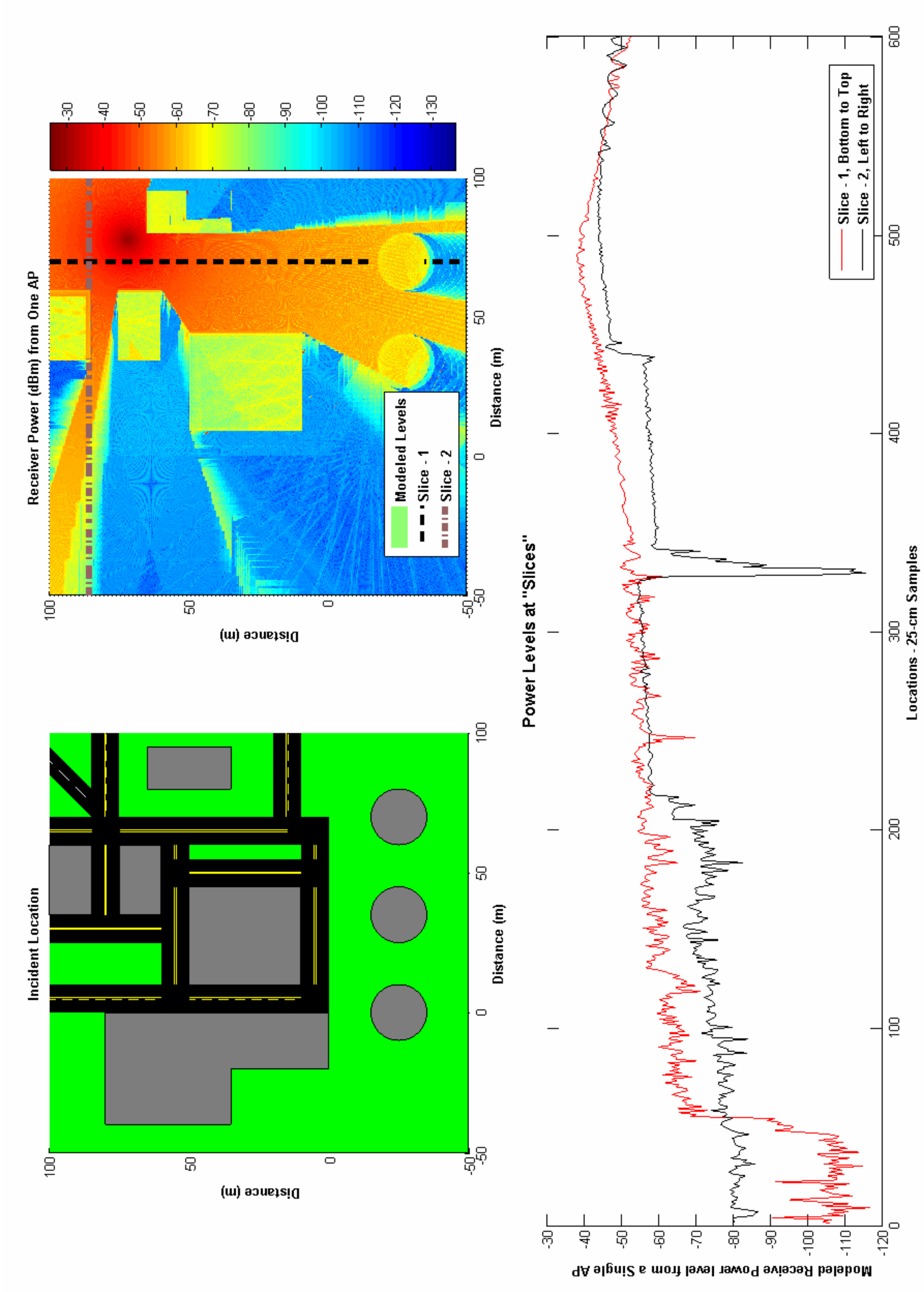


Figure 11: Difference (dB) between Model Used and Free Space Loss Model, Single AP Case

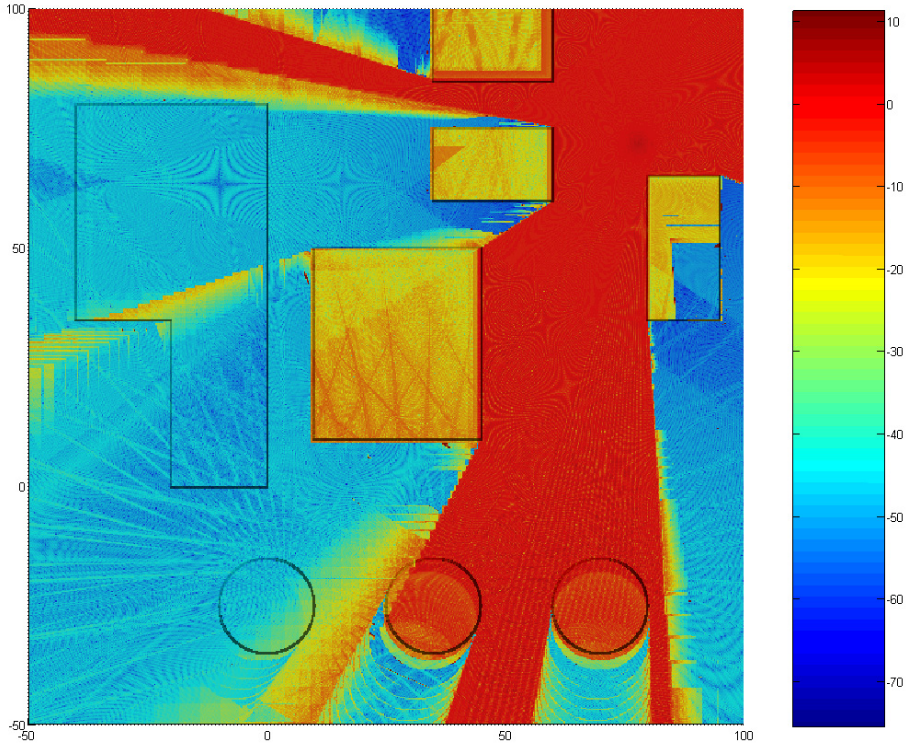
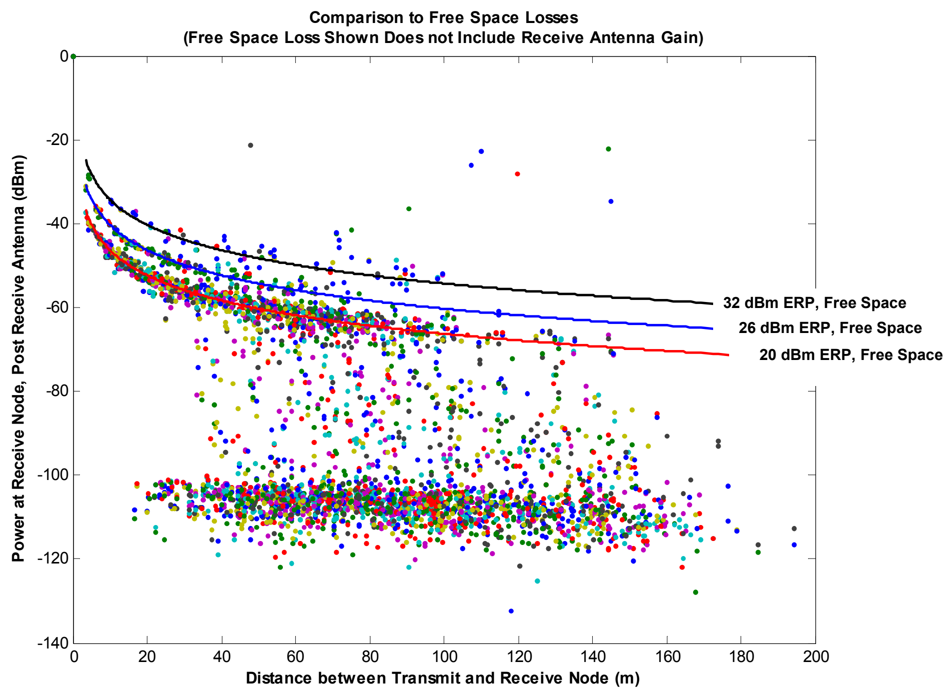


Figure 12: Difference (dB) between Model Used and Free Space Loss Model, Communications Nodes



Appendix B: PHY Data Rate Modeling Methodology

This section will detail the methodologies used to convert the RF signal and interference levels at each of the scenario's receiver node's to PHY data rate at the node.

Table 5 shows typical adjacent channel rejection performance and receiver sensitivity levels for the DSRC Standard – both which are measured quantities. These are essentially the same as IEEE 802.11 OFDM operating in a 10 MHz channel (and in fact these were derived from Table 91—Receiver performance requirements of the 802.11a Standard[8]).

Table 5: DSRC Receiver Performance (simto 10 MHz 802.11 OFDM)[9]

Data Rate, Mbits/s	Minimum Sensitivity, dBm	Adjacent Channel Rejection, dB	Alternate Adjacent Channel Rejection, dB
3	-85	18	34
4.5	-84	17	33
6	-82	16	32
9	-80	15	31
12	-77	13	29
18	-70	11	27
24	-69	8	24
27	-67	4	20

[8] *IEEE Std 802.11a-1999 (Supplement to IEEE Std 802.11-1999), [Adopted by ISO/IEC and redesignated as ISO/IEC 8802-11:1999/Amd 1:2000(E)], Supplement to IEEE Standard for Information technology Telecommunications and information exchange between systems, Local and metropolitan area networks Specific requirements, Part 11: Wireless LAN Medium Access, Control (MAC) and Physical Layer (PHY) Specifications, High-speed Physical Layer in the 5 GHz Band.*

[9] Designation: E 2213–02
ENGLISH
INTERNATIONAL

Standard Specification for
Telecommunications and Information Exchange Between Roadside and Vehicle Systems — 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications1
This standard is issued under the fixed designation E 2213; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (e) indicates an editorial change since the last revision or

A receiver noise floor level of *kTB + NF = -95 dBm* is assumed, with a 10 MHz equivalent noise bandwidth, a 10 dB receiver noise figure and another 1-dB of extraneous noise added as a conservative margin. This gives required PHY *S/N* levels of 10, 11, 13, 15, 18, 25, 26, and 28 dB, for corresponding PHY data rates of 3, 4.5, 6, 9, 12, 18, 24, and 27 Mbps. The adjacent channel rejection numbers imply effective Adjacent Channel Coupled Power Ratio[10] (ACCPR) levels of 25 (at 3-4.5 Mbps rates) to 33 dB (at 18 Mbps), which although consistent with earlier filings (25 dB ACCPR), also indicate that the IEEE 802 waveforms are much more robust to interference that simple ACCPR analyses would suggest. Again, note that these performance numbers are based upon measured results.

In determining the data rates at each node for each point in time, the following approach was utilized. First the signal power level received from the source node at the destination node is determined (see Appendix A: 4.9 GHz Radio Propagation Models). Then a determination is made as to what other packet activity is present during the packet transfer time duration, and what the pertinent[11] interference levels are received at the destination node. The data rate of each packet is then determined from Table 5 as a function of both the desired signal to noise level, and desired signal to interference levels. This process is then repeated for each packet, on each channel, and at each time step of the simulation. Packets that are lost are retransmitted.

This process captures the joint effects of interference and packet collisions on the four incident channels, and the effects that such collisions have on end user applications. In real life if several nodes produce interfering energy at the same time, then the effective data rates at the nodes will be reduced, but not necessarily to zero. Figure 13 and Figure 14 illustrate the mapping from received power levels to data rate for a single node AP case. In the full incident simulation up to four channel may be operating simultaneously, with source and destinations nodes following a given traffic distribution. This will be discussed next.

[10] The "effective" ACCPR can be computed from these values several ways. One is to sum the Adjacent Channel Rejection and the minimum C/N for each data rate, and subtract 3 dB. The other is to add the minimum sensitivity levels (in dBm) and Adjacent Channel Rejection levels, then subtract KTB + NF + 3 dB. These give equivalent results.

[11] "Pertinent" here considers adjacent channel utilization.

Figure 13: Example – Outbound Data Rate From One Mobile AP (Mbps)

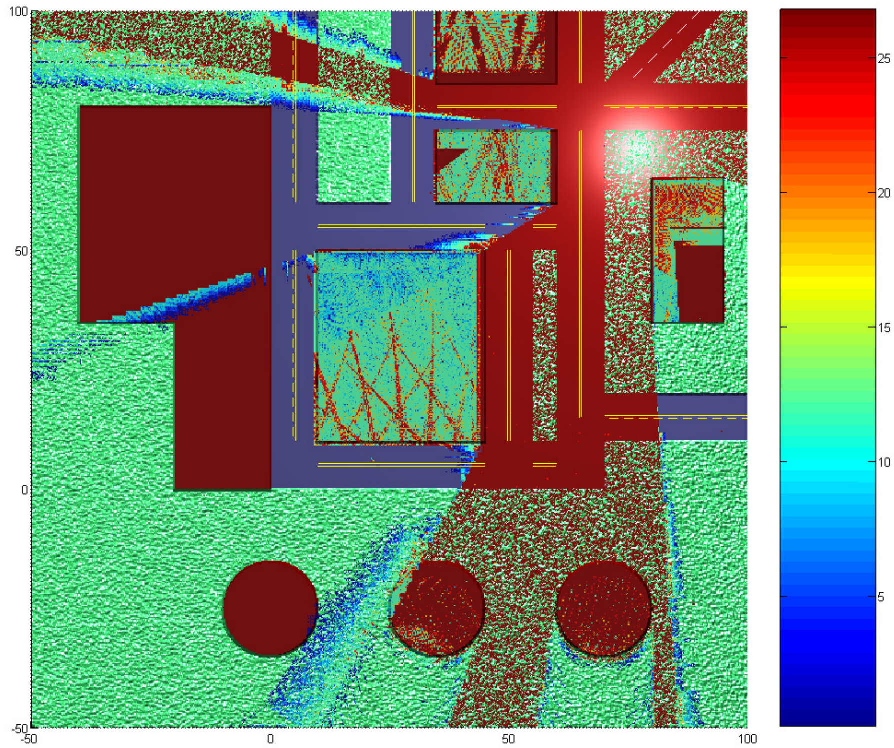
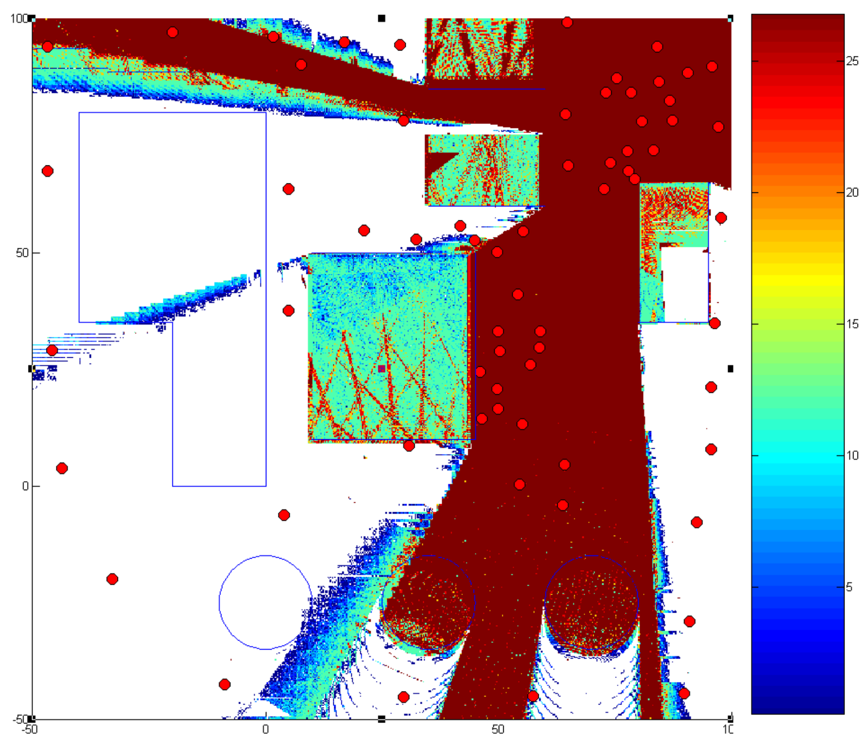


Figure 14: Example – Outbound Data Rate From One Mobile AP (Mbps)



NPSTC National Public Safety Telecommunications Council

Appendix C: Routing, Packet Distribution and Collisions

The final component of the incident simulation considers the temporal and spatial distribution of information flow at the incident scene. It is this information flow, mapped to spectrum resources, technology implementation, and radio propagation effects that collectively describe the aggregate impacts of Mask selection on the operational functionality of public safety communications, and the overall ability to effectively respond to an incident such as the one presented.

Once the signal and interference effects to and from each of the 65 nodes was computed, a 65 by 65 matrix was created to hold all possible desired and undesired signal levels. From this matrix the coverage of the ICC APs was determined, and that nodes that were not residing in covered areas were identified. Information transfer to these blocked nodes was then handled by mesh routing through other strategically located inter-service nodes at the incident scene. Note that no advanced routing techniques, such as dynamic frequency selection (DFS) or transmitter power control (TPC) was utilized – all routing nodes transmitted at the same power levels and on the same channel as nodes in direct contact with the ICC APs. The use of DFS and/or TPC would have dramatically reduced interference effects, and would also have significantly increased the capacity available at the incident. However, as we have already seen, neither capacity nor interference was a concern in this scenario – even with the “looser” emissions mask.

In order to capture packet data effects, the time scale of the incident was discretized into 108,000, 50 ms segments. For each channel, 40 % of these segments were randomly left without packet transfer activity, as technologies based upon carrier sense media access control[12] (MAC) typically cannot transfer information at greater than 60% channel capacity. The remaining traffic on each channel was randomly distributed (with no cross channel correlation) across the nodes according to the discrete distribution functions shown in Figure 15 (destination node component not shown).

For illustrative purposes, the final routing and traffic distribution for the police services channel is shown in Figure 16. In this figure the width of the lines connecting the nodes indicates the amount of traffic transferred being transferred between the nodes. Note that the mesh routing uses the same common channel resources to transfer (e.g. store and forward) information from node to node until the destination node is reached. A similar figure, Figure 17, is presented for all nodes, and all services/channels. Also note the tremendous amount of data being transferred between the bomb squad robot and its control point.

[12] IEEE us one of these technologies, utilizing a carrier sense multiple access scheme for both channel assess and collision avoidance.

Figure 15: Node/Channel Transmission Distribution

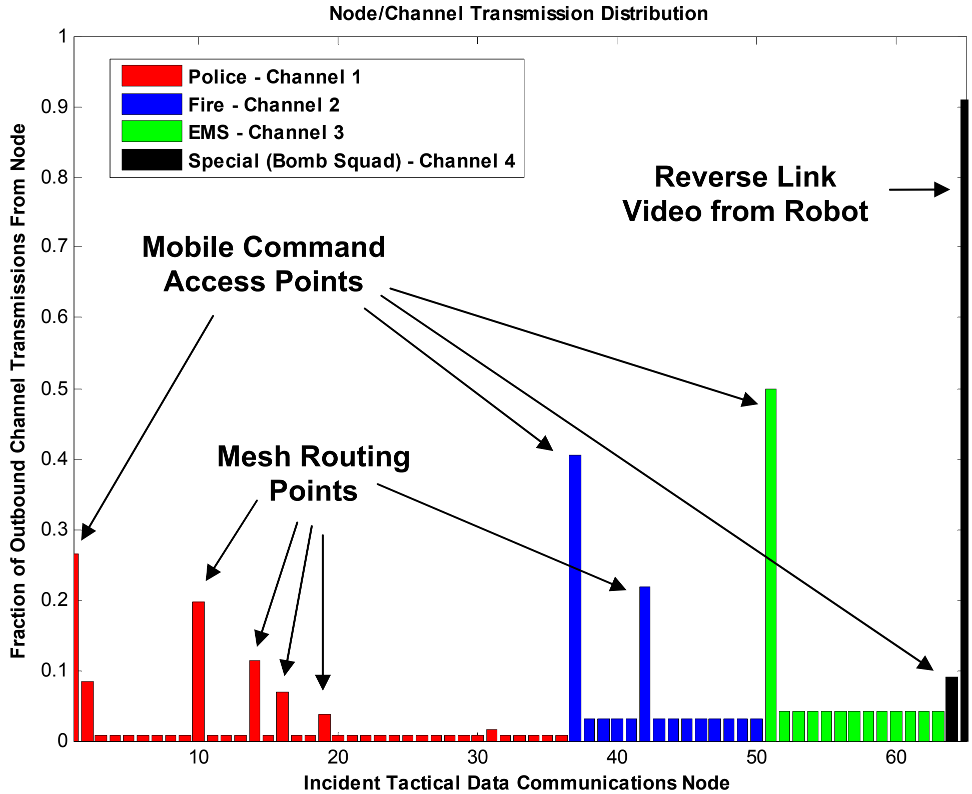


Figure 16: Tactical Data Routing for Police Services at Incident

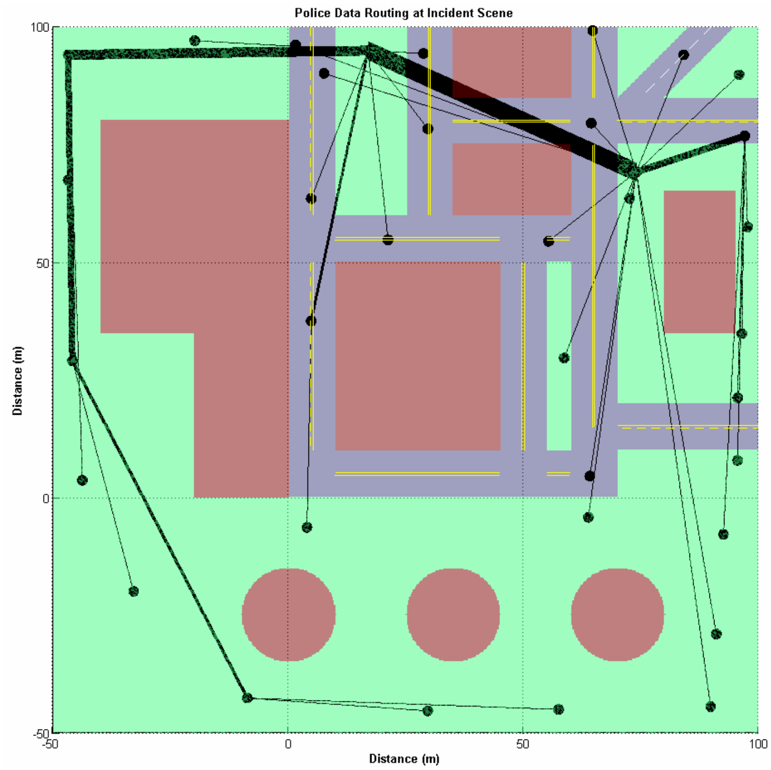


Figure 17: All Incident Tactical Data Links