Compensating Commercial Carriers for Public Safety Use: Pricing Options and the Financial Benefits and Risks*

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Abstract

Wireless broadband communication has the potential to revolutionize emergency response. While public safety wireless systems and commercial wireless systems have historically employed incompatible technologies, recent developments make it likely that both will adopt LTE technology, thereby creating a unique opportunity to supplement dedicated public safety infrastructure with roaming access to commercial networks. This was recommended in the FCC's 2010 National Broadband Plan but important details have yet to be addressed, including how commercial carriers will be compensated. Thus, this paper develops a cost model which is used to analyze the financial benefits and risks of enabling roaming access from both the perspective of public safety agencies and commercial carriers. It finds significant benefits associated with roaming, and some risks, which can in part be mitigated by the choice of pricing scheme. From public safety's perspective, the key financial benefit to priority roaming is the potential to deploy fewer costly cell sites by relying on roaming during periods of peak usage. Public safety agencies, when designing their networks, implicitly decide the worst-case scenario that can be supported. If the worst-case scenario prepared for would result in utilization levels of less than 10% (over the entire multi-year lifetime of the cell site), this paper demonstrates that the net present value (NPV) of total costs can be decreased by paying for more roaming services and deploying less dedicated infrastructure. Thus, the more severe the worst-case scenario planned for, the greater the cost savings roaming capability provides. Depending upon how roaming is structured, there are also potential risks. Enabling priority roaming could potentially lead to problems if public safety agencies have no incentive to use commercial capacity efficiently, or if roaming during unexpected events leads to costs that well exceed annual budgets, or if public safety roaming traffic reduces commercial revenue by displacing commercial subscriber usage and/or leading to increased subscriber churn. However, this paper shows that these risks are small or can be mitigated by choice of pricing scheme and, in particular, that a usage-based pricing scheme has several advantages over a flat-rate scheme. Usage-based prices provide an incentive for public safety agencies to deploy their own infrastructure when doing so is more cost-effective than roaming. If public safety pays commercial usage-based rates, this paper demonstrates that there is limited risk of public safety having to rein in usage due to cost during a serious localized emergency (as roaming costs would be orders of magnitude less than other public safety costs, such as personnel overtime). Furthermore, this paper shows that there is little financial risk to carriers if public safety pays commercial rates, since public safety roaming traffic could only increase carrier usage-based revenue and isn't overly likely to increase subscriber churn.

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* The authors gratefully acknowledge the financial support of the U.S. Department of Education's Graduate Assistance in Areas of National Need.

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All research presented here was performed at Carnegie Mellon University. Opinions expressed belong to one or both authors, and do not represent any other individual or organization.

1. Introduction

Wireless broadband communications can bring new and important functionality, such as streaming video and mobile internet access, to first responders who have traditionally had to rely on only narrowband voice communications (Peha, 2005; 2007a). While these new capabilities present a unique opportunity to revolutionize the way public safety users respond to emergencies, in order to realize this functionality, wireless broadband networks must be deployed (Hallahan & Peha, 2008; 2010b; Manner, Newman, & Peha, 2010; Peha, 2008). In the U.S., it is expected that public safety agencies will deploy their own dedicated networks, while commercial operators simultaneously deploy and operate their own commercial broadband systems. Additionally, since the public safety regions that have received waivers to begin deploying 700 MHz broadband networks (FCC, 2010c) and several major commercial operators (3G Americas, 2010)) have all indicated that their wireless broadband networks will based on the Long Term Evolution (LTE) technology standard, there is a unique opportunity for public safety users to utilize commercial networks.[1]

In particular, public safety roaming access to commercial networks can act as a valuable supplement to the services provided by a dedicated public safety infrastructure. Indeed, roaming access can yield a number of benefits, including: increased aggregate capacity, increased geographic coverage, and increased communications resiliency.[2] Additionally, as discussed in (Hallahan & Peha, 2010a), providing preferential treatment to public safety users when they roam on commercial networks (i.e. prioritizing public safety requests for network resources over the requests of other users) increases the degree to which public safety users can rely on commercial roaming (and thus the benefits derived from having enabling roaming access). In fact, the Federal Communication Commission's (FCC) National Broadband Plan (NBP) recommends that public safety be able to roam with priority access onto commercial networks so that, when necessary, commercial networks can supplement the service provided by public safety's own networks (FCC, 2010a). However, many of the specific details of the proposed roaming with priority access were left to be worked out.

Previous work (Hallahan & Peha, 2010a) studied some of the technical and operational issues associated with crafting roaming agreements between public safety agencies and commercial wireless carriers that would allow public safety users to roam with priority onto commercial LTE-based networks. However, one issue that has yet to be addressed is how commercial carriers will be compensated for public safety's use of their networks. Clearly there

[1] Historically, as discussed in (Hallahan & Peha, 2010a), public safety agencies have been unable to roam onto commercial networks seamlessly (i.e. using the same devices they use on their own networks). This is primarily because public safety and commercial systems have traditionally used incompatible technologies. Commercial carriers have typically built their networks to cover larger regions using commercial technology standards with performance and features targeted at consumers. Meanwhile, public safety agencies have typically designed systems to serve their own agencies and area of jurisdiction, using specialized technologies designed to meet the mission-critical needs of emergency responders (usually public-safety-grade land mobile radio (LMR) systems) (Peha, 2006; 2007b; Hallahan & Peha, 2009; 2011).

[2] Where commercial wireless service is available in addition to public safety wireless service, public safety will have access to increased aggregate capacity to support their activities when their own networks are fully loaded. In addition, where commercial wireless service is available but public safety service is not, public safety will have access to increased geographic coverage by roaming onto commercial networks in these areas. Finally, where commercial wireless service is available in addition to public safety service, public safety will have access to more resilient, fault-tolerant, and dependable communications capabilities in the event that something happens to their own network infrastructure

is some cost associated with providing service to public safety users and commercial carriers may expect to be compensated for that cost. If public safety users receive priority access over commercial users such that they supplant commercial communications that would have generated revenue, commercial carriers may expect to be compensated for that as well. To date, there has been little public debate about how commercial compensation should be structured. Thus, this paper will frame the important issues and provide analysis which can inform decision makers as they craft priority roaming policy.

Section 2 discusses the policy options for pricing public safety roaming access and discusses some of the potential tradeoffs between them. To assess these tradeoffs, a detailed model is developed to estimate the capital and operating costs of deploying dedicated, LTE-based public safety infrastructure. This model also calculates the costs due to public safety traffic roaming onto commercial networks, assuming a usage-based pricing scheme. Using this model, section 3 analyzes the financial benefits and risks of public safety roaming onto commercial networks from the perspective of public safety, while section 4 analyzes the financial benefits and risks from the commercial sector's perspective. To analyze these potential risks, a model is developed to calculate the utilization of commercial cell sites due to carrying public safety's traffic during emergency response scenarios. Finally, section 5 discusses the conclusions of this paper.

2. Pricing public safety roaming access: Options and tradeoffs

By making use of the PCRF network element and the PCC framework, a wide variety of pricing schemes are possible on an LTE-based network. As discussed in (Hallahan & Peha, 2010a), the PCRF is an optional network element which is responsible for policy decisions that affect the priority and preemption characteristics of each bearer. In addition, the PCRF provides a number of functions which enable operators to offer a variety of pricing schemes, including various ways of tying prices to network resource usage (e.g. measuring the duration a service is used, the aggregate data transferred, etc.). While there are many pricing schemes possible, they all fall into one of two categories: usage-based pricing or flat-rate pricing. A usage-based pricing scheme is a scheme wherein the amount charged for service is directly tied to the network resources consumed (e.g. $/GB). In contrast, a flat-rate pricing scheme is one wherein a set fee is charged for access to the network and the price paid does not directly change in response to network usage (e.g. $/subscriber).

Each of these schemes has fundamental tradeoffs. A flat-rate pricing scheme offers some cost certainty, but no incentive to make more efficient use of capacity. Cost certainty may be especially important to public safety agencies given the unique way in which they are funded. That is, these agencies are often constrained by limited budgets that are fixed well in advance, meaning they have little ability to respond to sudden increases in communications costs (e.g. in response to extra communications required to respond to large-scale disasters, which are very unpredictable). While flat-rate pricing may mitigate budget concerns, it does nothing to encourage public safety agencies to use limited resources (i.e. commercial wireless capacity) in a manner that is socially optimal. That is, flat rate pricing provides no incentive for public safety to deploy technologies that promote efficient use of capacity as costs are independent of how resources are used. For example, flat-rate pricing provides no incentive for public safety to invest in compression technologies that could lower their roaming usage, because that cost would not be recouped from lowered roaming bills. As another example, faced with a choice between deploying fixed video cameras that are wired or ones that are wireless (and roaming capable), flat-rate pricing gives public safety agencies no incentive to deploy the wired option, even if fixed video is not the best use of limited mobile broadband spectrum.

On the other hand, usage-based pricing provides an incentive for public safety agencies to make efficient use of capacity (as roaming costs are directly dependent on usage), but could also introduce a degree of cost uncertainty. That is, in response to serious emergencies, public safety can have highly uncertain and variable roaming costs if a usage-based pricing scheme is employed. This cost uncertainty could force government agencies whose budgets are set well in advance to ration public safety communications in harmful ways. In this case, harmful rationing means that public safety agencies rein in roaming usage due to cost when the number or magnitude of emergencies exceed what was expected when budgets were set, even if it is not socially optimal to do so. For example, if a hurricane strikes necessitating a substantial emergency response, usage-based pricing could lead public safety agencies to curtail roaming communications based on budget concerns, and this could potentially diminish public safety's ability to protect life and property.

A good pricing scheme will encourage decisions that lead users to use the right amount of resources (in this case, commercial capacity). However, a decision that leads to the right amount of resources being used on a day-to-day basis by public safety does not necessarily lead to the right amount of resources being used during an atypically large emergency. When it comes to technology decisions (e.g. whether to deploy wired vs. wireless fixed cameras) that are made with the day-to-day operations of public safety in mind, it is desirable that these decisions lead to efficient use of resources. Since these decisions are made well in advance of any specific incident they are, by definition, unrelated to the serious emergencies. In these situations, a usage-based pricing scheme leads to better resource usage. When it comes to decisions that are made with the response to a serious emergency in mind, it is desirable that these decisions not lead public safety to ration communications (i.e. rein in usage). Indeed, when emergencies occur that can't reasonably be planned for, and when there could be great social benefit in going beyond what was planned for, these are the times when it is least desirable to stick with a budget decision made well in advance. In these situations, a flat-rate pricing scheme eliminates the risk of rationing.

Thus, the situations in which there is risk in using a usage-based pricing scheme (i.e. during serious emergencies) are the exact situations in which there are benefits to using a flat-rate pricing scheme. Similarly, the situations in which there is risk in using a flat-rate pricing scheme (i.e. during normal, day-to-day operations) are the exact situations in which there are benefits to using a usage-based pricing scheme. By implementing a hybrid pricing scheme that is a combination of the two, it is possible to take advantage of these complimentary tradeoffs. That is, it is possible to structure a pricing scheme so that there is a default during normal operation, and a separate scheme that is activated based on certain circumstances. During routine operation, public safety could pay a fixed usage-based charge per unit of data transferred while roaming. Then, if a large-scale incident occurs that meets some predefined characteristics, an external trigger can activate a new pricing scheme that replaces the usage-based pricing (e.g. a flat-rate pricing scheme wherein the costs for the entire event are capped). (The FCC (2008) discussed several potential external triggers, such as a state-of-emergency being declared.) Such a hybrid scheme would have certain advantages. It would still provide incentives for public safety to make decisions to use limited commercial resources efficiently during routine operations (while costs are more certain), but lowers this risk that harmful rationing occurs during serious emergencies.

3. The Financial Benefits and Risks to Public Safety

This section investigates the financial benefits and risks of priority roaming from public safety's perspective. To do so, a model is developed to estimate the capital and operating costs of deploying dedicated, LTE-based public safety infrastructure and the costs due to public safety traffic roaming onto commercial networks, assuming a usage-based pricing scheme. Section 3.1 studies the benefits of being able to roam by using the model to investigate the tradeoff between the cost of deploying dedicated infrastructure and the cost of public safety roaming. Section 3.2 investigates the potential risks associated with roaming by investigating the costs associated with the emergency response to a serious localized-incident and a large-scale disaster that affects a wide area.

3.1. The Financial Benefits to Public Safety

As discussed in (Hallahan & Peha, 2008; 2010b; FCC, 2010d), several public safety requirements can affect the number of cell sites that need to be deployed in a public safety network. For a given area, the number of cell sites required depends on the capacity required by public safety users as well as the outdoor signal reliability required, the level of in-building coverage needed, and the cell-edge datarate requirements. This means that a minimum number of cell sites (and thus a minimum amount of capacity) needs to be deployed just to meet non-capacity-related requirements (i.e. coverage requirements). When the number of cell sites needed to meet coverage requirements exceeds the number of cell sites needed to meet capacity requirements, the network is referred to as coverage-constrained; otherwise the network is referred to as capacity-constrained.

From public safety's perspective, a key benefit of priority roaming access to commercial networks is that it provides choice when designing capacity-constrained networks. That is, with priority roaming as an option, public safety agencies don't have to deploy dedicated infrastructure to meet their peak capacity needs (i.e. beyond their coverage requirements), but instead can choose to deploy infrastructure to support capacity needs up to some point and rely on roaming beyond that. Traditionally, if public safety agencies wanted to ensure that there is sufficient capacity on a capacity-constrained network to carry all user traffic during the busiest period, enough dedicated infrastructure must be deployed regardless of how frequently all of that capacity is needed. With priority roaming as an option, public safety can base deployment decisions on minimizing cost. Put another way, where roaming is possible, the design that minimizes total cost may be a network that has dedicated capacity that is less than peak demand.

A flat-rate pricing scheme provides little incentive for public safety to build its own infrastructure (beyond what's needed to meet coverage requirements), even to support its routine traffic. Instead, public safety may minimize its costs by using roaming to support as much of its traffic as possible, even if it is not socially optimal to do so. (It is worth noting that in a public-safety-grade network, coverage requirements are typically much more stringent than in a commercial-grade network (Hallahan & Peha, 2008; 2010b) which means that a coverage-constrained public safety network will have significantly more capacity than would be expected in a coverage-constrained commercial network; roaming would only occur if public safety's needs are greater than the capacity provided by the coverage-constrained network.) With a usage-based pricing scheme, public safety has an incentive to deploy some of its own infrastructure as there is clearly a tradeoff between the cost of building additional cell sites and the avoided roaming costs associated with the traffic that would be carried on the commercial networks if those dedicated cell sites weren't deployed. Assuming a usage-based pricing scheme, a public safety network should be designed such that the cost associated with the amount of routine traffic that needs to roam is less than or equal to the costs of deploying an additional unit of infrastructure to alleviate that roaming (i.e. deploying an additional cell site). To quantify this tradeoff, a model is developed to estimate the capital and operating costs of deploying a dedicated LTE-based cell site and the costs due to roaming, assuming a usage-based pricing scheme.

More specifically, the net present value (NPV) of a cell site is calculated, where the NPV is defined as the total roaming costs that can be avoided by deploying the cell site minus the cost to build and operate that cell site over the time horizon planned for. In this analysis, the NPV of deploying a cell site with average utilization, *u*, over a time horizon, *n*, is calculated using equation 3-1 below. This equation assumes that a cell site is deployed initially for a fixed cost and then requires a fixed annual amount to operate. Additionally, this equation assumes that all of the traffic that this cell site carries (over the time horizon planned for) results in avoided roaming costs equal to the product of the total capacity of the cell site, the cell site's average utilization over its lifetime, and the price/GB for roaming traffic. All cash flows in future years are discounted at rate *D* to arrive at a single number for the present value of deploying the cell site.

$$NPV = \sum_{i=0}^{n} \frac{cf \cdot u \cdot P_i \cdot (T_{UP} + T_{DN})}{(1+D)^i} - \left(Capex + \sum_{i=0}^{n} \frac{Opex}{(1+D)^i} \right) \qquad (3-1)$$

Where:

u	Average cell site utilization over the time horizon	
cf	Conversion factor: change of units from Mbps to GB/year = 3,900[3]	
P_i	Price of roaming in the *i*th year	[$/GB]
T_{UP}	Uplink throughput per cell site	[Mbps]
T_{DN}	Downlink throughput per cell site	[Mbps]
Capex	Upfront cost to deploy a cell site	[$]
Opex	Annual cost to operate a cell site	[$/year]
n	Time horizon	[Years]
D	Discount rate	[%]

[3] cf = 3600*24*365/(1024*8) = 3900

The following tables summarize the input parameters used in this analysis. Table 1 presents the capacity parameters for a cell site in an LTE-based public safety network and Table 2 presents the range of costs for building and operating a public safety cell site. Table 1 is based on a network with 10MHz of spectrum available (which is consistent with public safety's 700MHz broadband allocation in the U.S., as of April 2011), where cell sites are sectorized into 3 sectors/cell, and spectral efficiency values consistent with an LTE-based network (City of New York, 2010; FCC, 2010b; 2010d). Table 2 provides 3 scenarios for the present value of the cost of deploying a cell site, assuming a 10-year time horizon and 8% discount rate for future cash flows (FCC, 2010b; Hallahan & Peha, 2009).

Cell Site Capacity Parameters			
	Uplink	Downlink	Units
Spectrum/Sector	5	5	MHz
Spectral Efficiency	0.5	1.5	b/s/Hz
Throughput/Sector	2.5	7.5	Mbps
Sectors/Cell	3	3	
Throughput/Cell	7.5	22.5	Mbps

Table 1: Representative capacity parameters for a cell site in an LTE-based public safety network

Cell Site Cost	Low	Average	High
Capex - (upfront cost)	$ 100,000	$ 300,000	$ 500,000
Opex - (annual costs)	$ 10,000	$ 30,000	$ 50,000
PV of Costs	**$ 167,000**	**$ 500,000**	**$ 835,000**

Table 2: 3 scenarios for the present value (PV) of the cost of deploying an additional cell site in a network

Fig. 1 plots the NPV of deploying a cell site as a function of its average utilization. In this analysis, the price of roaming is initially $10/GB (in line with the commercial price for 700MHz LTE service in the U.S. (Verizon, 2011)), but declines at a rate of 15% each year[4] (e.g. cost in tenth year = $2.32/GB). Three scenarios for the cost of deploying a cell site (as given in Table 2) are plotted, in addition to an upper[5] and lower[6] bound.

[4] In the U.S. from 1999 to 2008, voice revenue per minute fell from $0.22 to $0.05; a decline of about 77%, or about 15%/year (FCC, 2010e). In comparison, Tellabs (2011) predicted that $/GB will fall approximately 80% over the next 5 years. While this rate of decline is more aggressive than that modeled in this paper, their starting valuing of about $25/GB is well above the starting value used in this paper ($10/GB). Their analysis predicts a revenue/GB of about $5/GB in 2015, which is consistent with starting at $10/GB and declining by 15% each year.

[5] The upper bound is based on a low cell site cost of $167,000 and a high roaming price of $10/GB for all 10 years.

[6] The lower bound is based on a high cell site cost of $835,000 and a low roaming price of $2.3/GB for all 10 years.

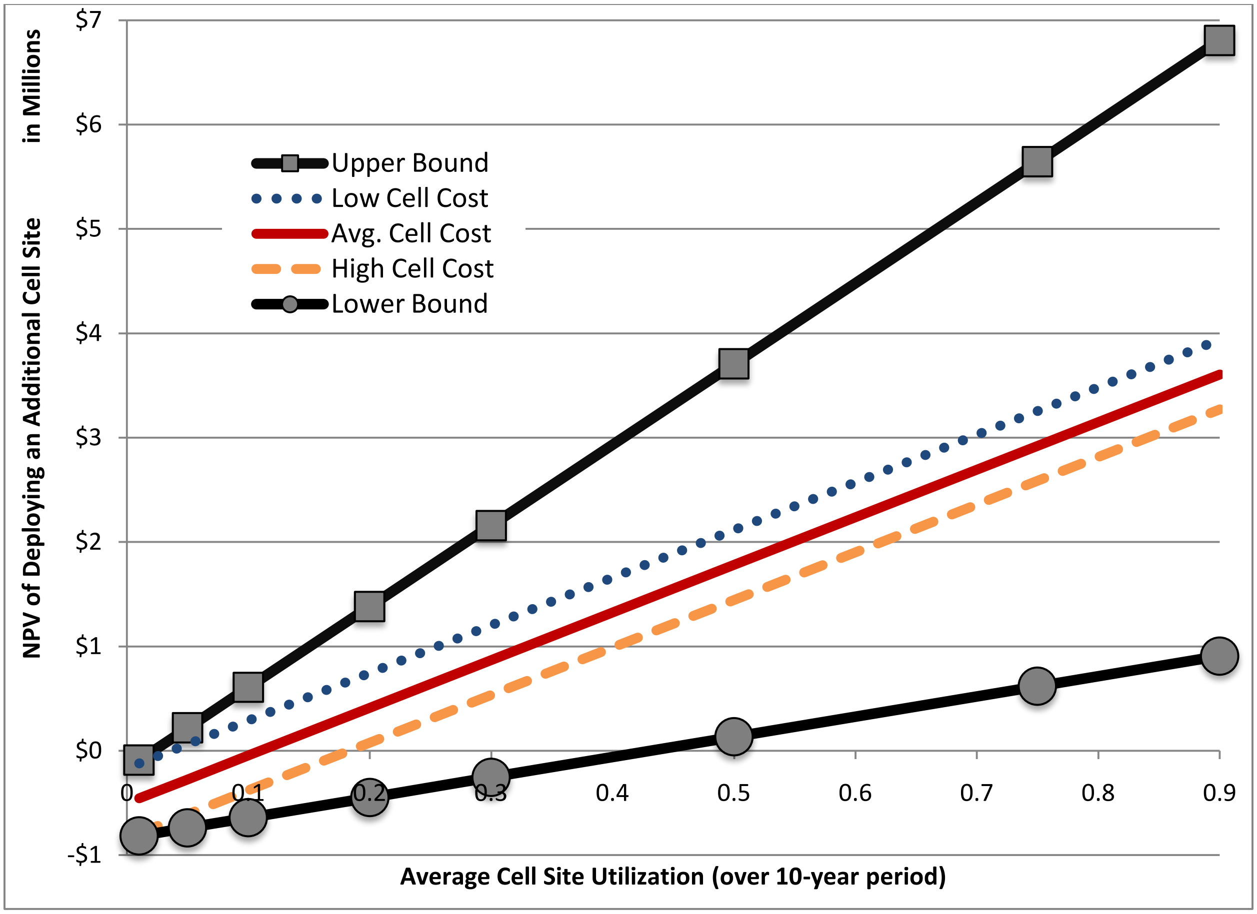

Fig. 1: The NPV of deploying a cell site as a function of its average utilization over a 10-year period.

A cell site's utilization will vary over time. This is because there are routinely busy periods when usage peaks, and off-peak hours when utilization is much lower. In addition, during critical incidents (on a public safety network in particular) there can be times when the capacity demanded by emergency responders spikes to levels far greater than what is typical. Designing for higher capacity without roaming means deploying greater amounts of dedicated infrastructure, and this means that larger emergencies can be handled. As more dedicated infrastructure is deployed, the lower the average utilization is going to be on that infrastructure. With roaming as an option, public safety could, for example, build out its dedicated infrastructure to meet its routine capacity needs (or routine needs in off-peak hours), while using roaming to support the serious incidents (or busy periods) that require additional capacity to support; this would increase average utilization of the dedicated infrastructure that was deployed. In more precise terms, public safety designs their networks such that the probability of an incident that requires more capacity than can be supported occurring during the network planning horizon is less than p (where p is small[7]). With roaming as an option, public safety can deploy less dedicated infrastructure and still achieve the same probability p, compared to a scenario in which roaming is not possible. (It is important to note that, as discussed earlier in this section, when network planners make infrastructure deployment decisions there are

[7] While p can be made small, under real-world conditions, designing a network such that $p = 0\%$ is impossible.

additional factors to consider besides the capacity needed; a minimum level of dedicated infrastructure will be required just to meet public safety coverage requirements.)

Fig. 1 shows that the NPV of deploying a cell site increases linearly with its average utilization over the 10-year time horizon. For an average cell site cost and roaming prices that are consistent with what commercial users pay, the breakeven threshold for average utilization is about 10%. When average utilization is expected to be higher than 10% it is cost-effective to deploy the cell site; when average utilization is lower than that, it is more cost-effective to have all of the traffic that would have been carried by the cell site roam onto commercial networks instead.

There are three major factors that influence how utilization varies over time: (1) the pattern of public safety's traffic throughout the day, (2) the growth of public safety's usage over the years, and (3) the magnitude of emergency the dedicated network is designed to support. As for the first factor, public safety's traffic varies from one instant to the next in uncertain ways as it depends upon a population of independent users who can choose to utilize a variety of mobile applications, each requiring different datarates, at different times depending on their current circumstances. During periods when many users are using high datarate applications, utilization on the network peaks; the more often this occurs, the greater average utilization will be. As for the second factor, in this analysis, network planning decisions are made for a 10-year time horizon. Over the course of the 10-year period, public safety usage will likely grow in unknown ways. This is because new applications will likely be developed for public safety use on mobile broadband networks, capacity requirements of existing applications may change, and because these applications will likely be increasingly integrated into public safety's operations. And as usage grows, the average utilization increases. Since public safety agencies are just now beginning to deploy broadband networks, there is little detailed historical data available to project future traffic patterns and usage growth. Since these factors can dramatically affect average cell site utilization, and thus the decision of whether or not to build infrastructure or roam, it is important that further studies be done on public safety usage of wireless broadband.

Of the three factors that affect average utilization, the only one that is a design decision (as opposed to a factor with some uncertainty beyond the designer's control) is the magnitude of emergency response that the network is designed to support (e.g. once-a-month incident, once-a-year incident, once-a-decade incident, etc.). The network designer can control the scale of emergency designed for by controlling the amount of dedicated infrastructure deployed (and thus the amount of dedicated capacity available). The larger the emergency planned for using dedicated infrastructure, the lower the average utilization will be on that infrastructure. The following is a simplified example to provide some context. Assume a network planner has a projection, x, for the average capacity required by public safety in the network coverage area (e.g. in Mbps/km^2). Further, assume he can neglect how public safety's usage changes and grows over time. If the breakeven average utilization threshold is 10% (as given in Fig. 1), then it is not cost-effective to deploy dedicated infrastructure to support an emergency that requires capacity greater than $10x$. (That is, if the network is designed to support emergencies requiring 10 Mbps/km^2 and average capacity used is only 1 Mbps/km^2, then average utilization would be 10%.)

Fig. 1 also shows that the exact value of the breakeven threshold for average utilization depends on the cell site cost and price paid for roaming: as cell site costs increase and/or roaming prices decrease, the more cost-effective roaming becomes. For instance, if cell site costs are high instead of average, the average utilization threshold increases to 20%. Additionally, if cell costs are high and the price of roaming is about 75% lower than what commercial users pay, the average utilization threshold is about 40%. To provide a little context for this effect, if only the magnitude of emergency planned for is considered (i.e. neglecting how usage changes and grows over time), an average utilization threshold of 40% means that dedicated infrastructure should be deployed to support emergencies that require 2.5*x* the capacity that is utilized on average (compared to 10*x* with a utilization threshold of 10%), while the additional traffic from larger emergencies can be handled more cost-effectively through roaming.

3.2. The Financial Risks to Public Safety

From public safety's perspective, a key financial risk associated with a usage-based pricing scheme for roaming traffic is that it could lead to large, unexpected costs during emergency responses and that this could lead public safety to ration communications in harmful ways. To investigate the potential usage-based roaming costs associated with an emergency response, this section analyzes two categories of incident response: the response to a highly localized critical incident (wherein many first responders converge to a small area, potentially exceeding the available dedicated capacity) and the response to a large-scale wide-area disaster (wherein many first responders are active over a large region and roaming is needed because it occurs outside the coverage area of the dedicated network and/or the dedicated infrastructure was damaged during the disaster).

In the analysis of the response to a localized-emergency, two scenarios for public safety traffic are studied: one based on a hypothetical emergency response in New York City (City of New York, 2010) and another based on a hypothetical emergency response in Washington D.C. (Spectrum Coalition for Public Safety, 2005). The former response scenario centers around a "dirty-bomb" detonated in downtown New York City causing about a thousand casualties, while the latter response scenario involves a terrorist attack on Washington D.C. The hypothetical events were designed to illustrate a 'worst-case' capacity scenario in which thousands of first responders are concentrated in a small area, served by a limited number of cell sites. Table 3 summarizes the relevant capacity parameters from these two events.

	Total Incident Demand		**Busiest-Sector Demand**[8]	
Scenario	Downlink	Uplink	Downlink	Uplink
New York City Incident Response	60 Mbps	16 Mbps	20 Mbps	5.3 Mbps
Washington D.C. Incident Response	42.9 Mbps	13.7 Mbps	4.8 Mbps	1.5 Mbps

Table 3: Summary of capacity parameters for two hypothetical emergency responses to highly-localized incidents

[8] The City of New York (2010) analysis assumes that the total incident is evenly spread across three cell sectors; thus there are three 'busiest cell sites'. In the Washington D.C. scenario, only the capacity required at the busiest cell site is given, thus the capacity required in the busiest sector is calculated assuming 3 sectors per cell site.

For the New York City scenario, two levels of roaming are analyzed. In the partial roaming case, only the capacity demand on the three busiest cell sectors that exceeds what can be supported by those sectors has to roam. No partial roaming case is calculated for the Washington D.C. scenario since there is sufficient capacity in an LTE sector (based on the cell site capacity parameters discussed in section 3.1) to support the busiest sector of the D.C response. (In the initial NYC analysis, it was assumed that the 'dirty' bomb scenario would be localized to an area that is covered by 3 sectors. The FCC (2010d) noted that given the recommendations of the NBP, it is more likely that the same area would need to be covered by approximately 9 sectors in order to meet coverage requirements (as discussed in section 3.1). However, in their analysis of the 'dirty' bomb scenario, the FCC (2010d) made the conservative assumption that the area is covered by 6 sectors. Even with this assumption, the FCC found that the dedicated public safety infrastructure provides sufficient capacity to support the 'dirty' bomb scenario. Thus, to create a scenario in which roaming is necessary, the analysis in this section studies the worst-case for the 'dirty' bomb scenario wherein only 3 sectors cover the affected area.) In the full roaming case (calculated for both the New York City and Washington D.C. scenarios), the total incident capacity roams (i.e. the dedicated public safety infrastructure carries no incident traffic). Fig. 2 plots the roaming costs expected in these three scenarios as a function of the duration of the emergency response.

To put the roaming costs in context, Fig. 2 also includes estimates for the incremental personnel cost of responding to such a localized emergency. Fig. 2 plots two scenarios for the incremental personnel cost of an emergency response based on overtime costs. Overtime costs are calculated assuming the average pay for a first responder is $35/hour (about $72K per year),[9] overtime pay is 1.5*x* the regular hourly pay (U.S. Department of Labor, 2008), and 1,400 public safety users are involved in the response.[10] In the first scenario, all users that respond are on duty when the incident occurs and remain on-duty for the duration of the response. To account for the fact that users on duty may not receive overtime pay during their normal shift, it is assumed that incidents are uniformly distributed and thus occur with equal probability throughout each 8 hour shift (with overtime pay required for the hours worked beyond the 8 hour shift). For the second scenario, all users that respond to the incident must be called up from being off duty (so that every hour of the response they are paid overtime).

[9] This is in line with the personnel costs in past NYPD budgets (New York City Independent Budget Office, 2006)
[10] This is consistent with the number of local first responders involved in the response in the Washington D.C. scenario (Spectrum Coalition for Public Safety, 2005). That response also called for an additional 1,000 federal responders as well, but they aren't included in this analysis. While the NYC analysis (City of New York, 2010) makes no explicit mention of how many first responders would be involved, 1,400 users appears reasonable. The scenario assumes approximately 900 people are injured and both EMS and fire personnel are involved in their evacuation and treatment. In addition, the scenario assumes that the NYPD initiates a level 4 mobilization, which fields about 1,000 officers according to (National Commission on Terrorist Attacks Upon the United States, 2004).

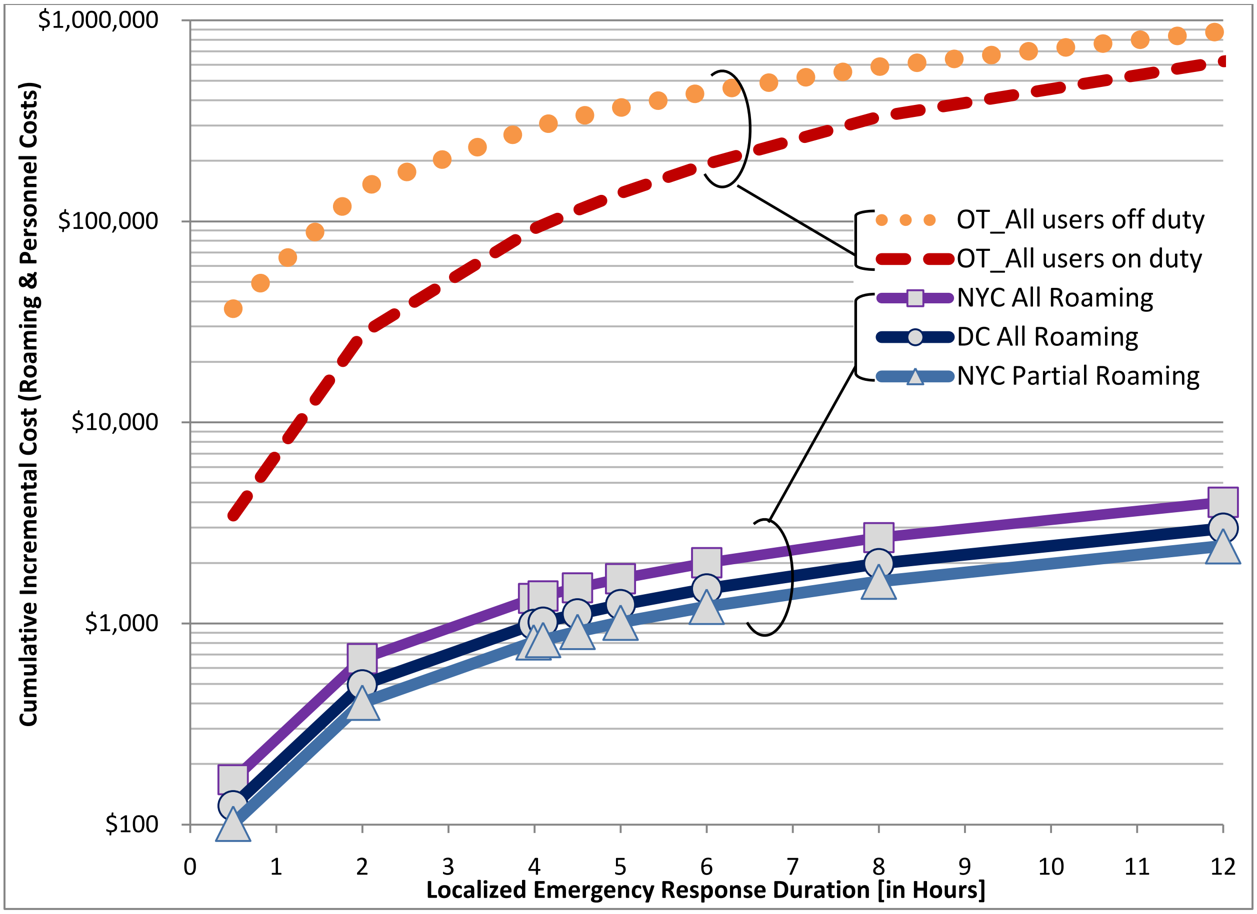

Fig. 2: Three scenarios for the roaming costs associated with an emergency response during a localized critical incident

Fig. 2 shows that the roaming costs associated with a localized emergency response, even in the worst case modeled, are about $200 – $300 per hour. This means the roaming costs associated with the occasional response to a localized emergency are unlikely to significantly strain the budgets of the responding agencies. In comparison, personnel costs associated with paying overtime to responders involved in the emergency response are on the order of $10,000 – $75,000 per hour; a couple of orders of magnitude greater. (While seemingly high, these overtime cost estimates are consistent with what the New York police and fire departments routinely budget for overtime costs (New York State Financial Control Board, 2010), about $70,000/hour.[11]) This means that not only are the roaming costs associated with the response to a localized-emergency small compared to public safety's budgets, these roaming costs are small even if only compared to the other costs associated with responding to a localized-emergency. Thus, usage-based prices along the lines of what commercial users pay are not overly likely to lead to public safety rationing communications when localized-emergencies occur.

[11] In 2011, New York City anticipates overtime costs of $413 million and $174 million for the police and fire departments, respectively (New York City Comptroller, 2010). To put these overtime projections in perspective, the NYPD and FDNY have operating budgets for 2011 of about $4.2 billion and $1.5 billion, respectively (New York City Office of Management and Budget, 2011a; 2011b).

In addition to a localized-emergency (where the geographically focused nature of communications demand can result in roaming because the available public safety cell sectors are overwhelmed), this paper also studies the potential roaming costs that could occur during the response to a large-scale wide-area disaster, to assess the financial risk posed to public safety agencies. This analysis is based on the work done in (FCC, 2010d) wherein the FCC studied a disaster scenario derived from the response to Hurricane Ike. In the FCC's Hurricane Ike scenario, there are 14,991 emergency responders using the network during the peak period, spread across 426 public safety cell sites. In the FCC's analysis, these users would generate a load of 0.59 Mbps in the uplink and 0.94 Mbps in the downlink (per cell sector), if spread uniformly across the network. The FCC also studied two extensions of this base case, one in which the capacity required doubled and a second in which the capacity required quadruples, as summarized in Table 4.

Scenario	PS Responders	Cell Sites	Cell Sectors	Utilization		Throughput [Mbps]	
				Uplink	Downlink	Uplink	Downlink
Base Case	14,991	426	1278	18.7%	12.9%	0.59	0.94
2x Base Case	29,982	426	1278	37.3%	25.8%	1.19	1.89
4x Base Case	59,964	426	1278	74.7%	51.6%	2.37	3.78

Table 4: Summary of three scenarios for the capacity required for the emergency response during a hurricane

In comparison to the Washington D.C. localized-emergency scenario, the FCC Hurricane Ike scenario assumes a much higher capacity is required per first responder. However, in the analysis by the FCC (2010d), these users are spread out over a much larger area so that the capacity per sector is actually lower. Furthermore, according to that same FCC analysis, a public safety LTE network should have sufficient capacity to meet the communications demands during the Hurricane Ike scenario. This implies that limited, if any, roaming should be necessary as long as the public safety infrastructure is available for a disaster response along the lines of Hurricane Ike. However, it is possible that during a large-scale disaster like a hurricane, some of the public safety infrastructure is damaged and thus roaming would be necessary. (While it is unlikely that a disaster that damaged the hardened public safety network did not damage the commercial infrastructure, the fact that there are multiple commercial networks increases the likelihood that some of it would have survived and be available for roaming). Additionally, it is possible that a disaster could occur in a region that is not covered by public safety infrastructure but is covered by commercial networks.

To study the potential roaming costs during a large-scale disaster, Fig. 3 plots the cost of roaming as a function of the duration of the response, assuming half of the capacity in each of the 3 scenarios in Table 4 roams on commercial networks. Such a scenario is consistent with a disaster striking a region covered by a dedicated public safety network and damaging a substantial portion of the dedicated infrastructure such that half of the total capacity required in the response ends up roaming on commercial networks. The FCC (2010d) analysis of Hurricane Ike studied an emergency response occurring in a populous region near Houston, TX. Given the proximity to a population center, the number of responders expected to participate is likely larger than would be expected in a more sparsely populated region. Indeed, as was shown by Hallahan and Peha (2008), the number of first responders in an area is linearly related to the population in that area. Thus, the scenario studied in this section is also consistent with a disaster striking a more rural region that is not covered by dedicated infrastructure, and results in a response about half the size of one that occurs in a more populated region.

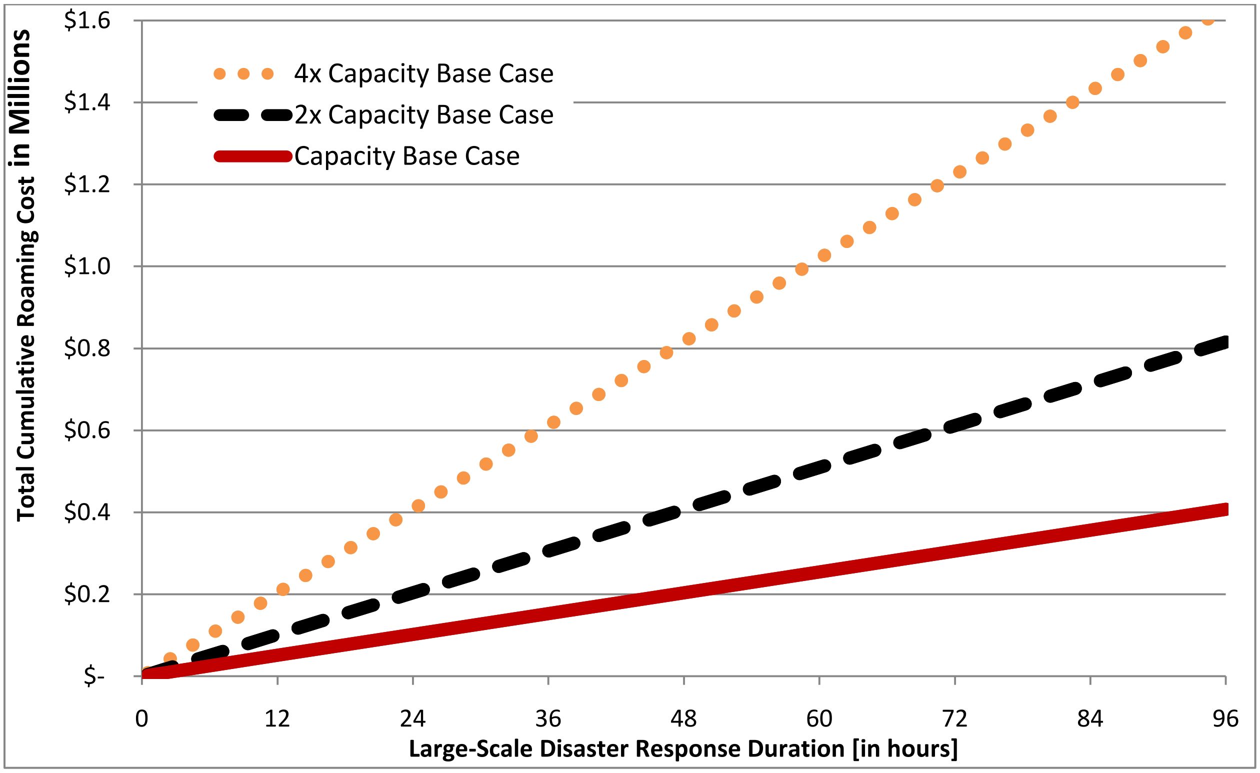

Fig. 3: The cost of roaming as a function of the duration of large-scale disaster emergency response, for 3 scenarios.

The key difference between the response to a large-scale disaster and a localized-emergency is that the former will likely involve many more first responders and occur over a much larger area. Thus, given the much greater scope of the emergency response, the fact that the costs presented in Fig. 3 are greater than those estimated in the localized-emergency scenario is expected. Indeed, in the base case, a response that lasted for 3 days could cost about $0.25 million. (As demonstrated for a localized-emergency, the overtime costs associated with such a response would be a couple of orders of magnitude greater than the roaming cost.) While significantly less than the associated personnel costs, $0.25 million in roaming costs could still be a significant burden for responding agencies to deal with. Indeed, there is a risk in this scenario that the potentially large roaming costs could force public safety agencies to rein in usage, even if it's not socially optimal to do so. Admittedly, such a scenario is likely to occur rarely (as it requires both a rare, large-scale disaster to occur and the unavailability of the dedicated infrastructure). However, given the potential for a usage-based pricing scheme in such a scenario to harm public safety (e.g. by forcing public safety to ration communications), it may make sense to handle infrequent but significant roaming costs associated with large-scale disasters in a different way. As discussed in section 2, one way to handle these infrequent but potentially costly events is to have a hybrid system wherein prices change in response to certain triggers (e.g. state-of-emergency is declared). For instance, a flat-fee could be invoked when the disaster strikes, mitigating any potential harm from usage-based pricing in that scenario, while still preserving the incentives usage-based pricing provides during more routine use. An alternative approach to handling these types of large, infrequent events would be to use other funding sources to pay for roaming costs, instead of the annual public safety budget (e.g. federal disaster relief funds).

4. The Financial Benefits and Risks to the Commercial Sector

The presence of public safety roaming on commercial networks has the potential to affect both commercial carriers and their subscribers. On a commercial wireless network, the impact to commercial subscribers is usually measured in terms of blocking rates (for real-time services like voice) and congestion (for data connections). With regards to the effect that public safety roaming has on commercial subscribers, the key question is whether, as a result of public safety roaming traffic, utilization on the commercial network gets sufficiently high resulting in unacceptable levels of congestion. The level of utilization depends upon the scenario in which public safety is roaming: public safety day-to-day traffic roaming routinely versus public safety traffic roaming in response to a localized emergency versus public safety traffic roaming in response to a large-scale wide-area disaster. Routine public safety traffic is unlikely to significantly affect commercial network utilization, as carriers can design their networks with appropriate capacity to support expected, routine traffic. However, utilization during the response to serious emergencies may be an issue. To better quantify the risk both commercial carriers and subscribers face due to public safety roaming during emergencies, a model is developed to estimate commercial network utilization due to public safety roaming traffic during two emergency scenarios.

In Fig. 4, the average uplink and downlink utilization on a commercial cell sector due to carrying public safety traffic is plotted as a function of the commercial spectrum available on those networks with roaming agreements with public safety. Two scenarios are studied. One wherein 10 Mbps roams in the downlink and 2.7 Mbps roams in the uplink. This is consistent with the NYC localized emergency scenario described in 3.2, with all the public safety traffic uniformly spread across 6 sectors as discussed in (FCC, 2010d). The other scenario is based on the base case large-scale disaster scenario summarized in Table 4, wherein all the public safety traffic in a sector roams (0.94 Mbps in the downlink, 0.59 Mbps in the uplink).

This analysis assumes that the density of cell sites in each wireless carrier’s network is equal to the density of cell sites in the public safety network. This assumption is a reasonable first-order approximation given that the number of cell sites in each major carrier’s network is roughly equal to the number of cell sites recommended by the NBP for a nationwide public safety network (i.e. all 4 major networks have about 40,000 to 50,000 cell sites nationwide (Morgan Stanley, 2009) while the NBP calls for about 44,000 cell sites in a nationwide public safety network). (While the total number of cell sites is similar, this is still a very rough approximation. In particular, the total area covered as well as the distribution of cell sites throughout rural and urban areas isn’t necessarily the same on commercial and public safety networks. Exact estimates would require detailed data on the exact locations of all cell sites in the commercial networks, and the design of a public safety network that has to be built. Nevertheless, this approximation can still give useful insight as to the order of magnitude of utilization levels for a couple emergency scenarios.) Also, it is assumed that the spectral efficiency on the commercial network is equal to the spectral efficiency on the public safety network, which seems reasonable given that both networks must support the same LTE technology to facilitate roaming as envisioned in this paper.

While it is unlikely that public safety devices will be designed to roam outside the 700MHz band, this analysis includes all of the spectrum that is available for mobile broadband on commercial networks that have roaming agreements with public safety. This is because when a commercial operator has spectrum at 700MHz and spectrum elsewhere, its customers can be shifted to other spectrum bands outside of 700MHz, even if public safety subscribers can't. Fig. 4 plots average sector utilization when anywhere from 20MHz to 450MHz available for commercial mobile broadband (where the *x*-axis represents the amount of spectrum in use by those commercial carriers that have roaming agreements with public safety). This is reasonable as there is 547 MHz below 3.7 GHz that is currently licensed as flexible use spectrum that can be used for mobile broadband (FCC, 2010b). Additionally, of the commercial spectrum available below 2.5GHz, the two largest commercial carriers currently average roughly 100 MHz in the major markets and the next two carriers average about 50 MHz in these markets (Morgan Stanley, 2009).

Now, not all of the spectrum that is currently available has been deployed yet[12] and not all of it is used for mobile broadband (i.e. some is used for voice traffic). Indeed, the FCC's analysis assumed that approximately 33% of available spectrum was used for mobile broadband in 2009, and projected that 50% would be used for mobile broadband in 2010, 65% in 2011, and 75% in 2012 (FCC, 2010b). As a baseline, this paper investigates the utilization due to roaming public safety traffic when 60 MHz of commercial spectrum is available for mobile broadband. This is consistent with public safety having a roaming agreement with one of the two largest carriers in the U.S. (or both of the 2nd tier carriers) and the carrier(s) using about 60% of available spectrum for mobile broadband.

[12] 377 of the 547 MHz of spectrum that is available was auctioned or rebanded within the past six years, meaning that most of it is just now starting to be put into service for mobile broadband.

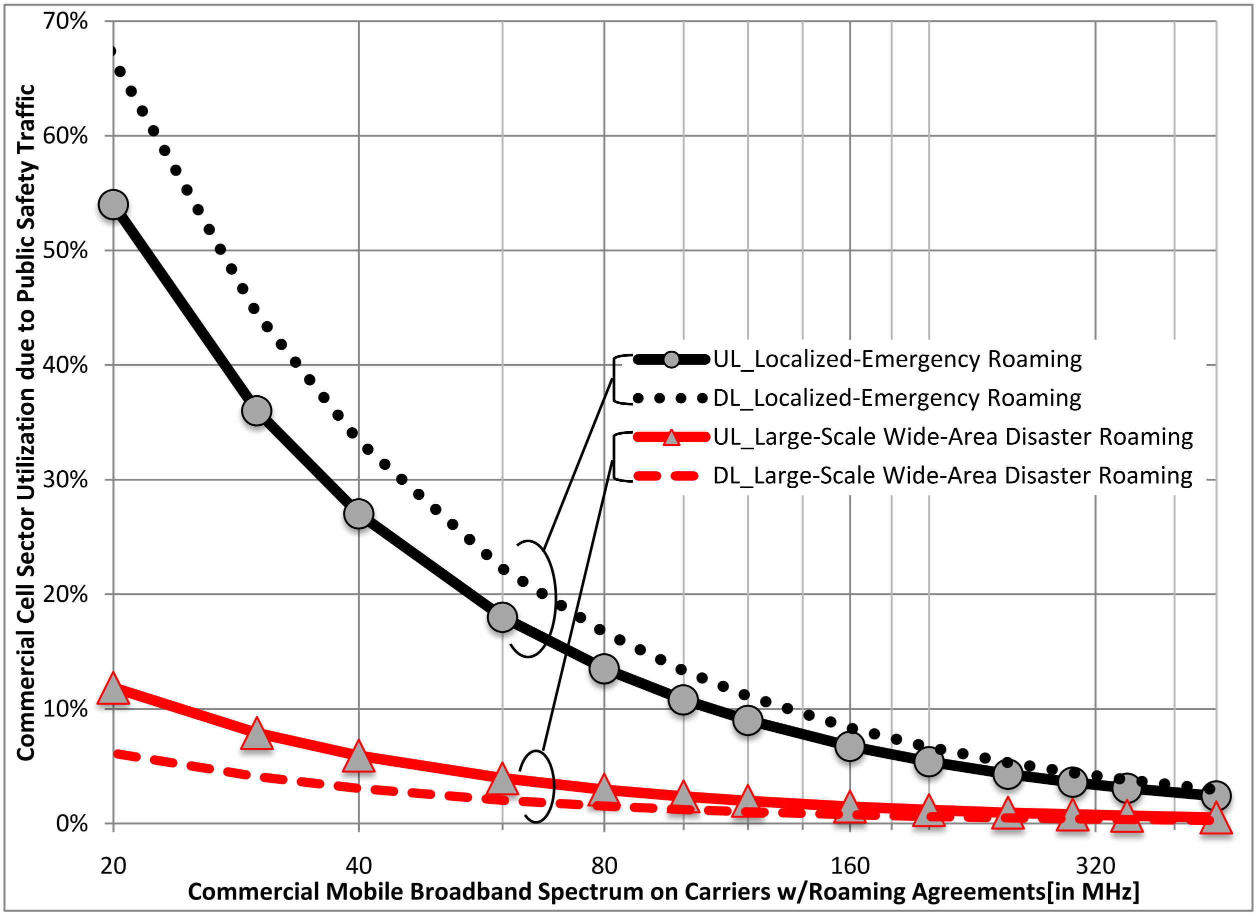

Fig. 4: Average commercial network utilization due to public safety roaming during a large-scale disaster response

Fig. 4 shows that if 60 MHz is available for mobile broadband on the networks that public safety has roaming agreements with, even adding all of public safety's traffic to the commercial network in the large-scale wide-area disaster scenario studied (the bottom two curves), public safety traffic would only utilize 4% and 2% of the commercial capacity in the uplink and downlink of each affected sector, respectively. Even if only 20 MHz was available for broadband on those networks, roaming utilization would still only be about 10%, in this particular scenario. This level of utilization is low. While it is possible that on some cell sectors for relatively brief periods of time the utilization due to public safety traffic could increase above these utilization levels, on average during the disaster response scenario studied, public safety's roaming traffic is unlikely to overwhelm the available commercial infrastructure. Thus, the risk that commercial subscribers experience unacceptable levels of congestion during the large-scale disaster scenario studied is low.

As for the impact on commercial subscribers during a localized-emergency scenario, the risk of congestion in the affected cells is likely higher than in the large-scale wide-area disaster scenario. According to Fig. 4, with 60 MHz of commercial spectrum available for mobile broadband, if all of the traffic roams for the localized-emergency scenario, about 22% and 18%

of commercial capacity would be utilized by public safety traffic in the downlink and uplink, respectively. To put this level of utilization in context, while it is higher than the utilization in the large-scale disaster scenario, it is still below the level at which public safety priority access is capped on voice systems that support the Wireless Priority Service (the WPS system caps priority access at 25% of available capacity, as discussed in (Hallahan & Peha, 2010a)). Thus, for this particular type of localized incident, there is some risk that the commercial subscriber's experience in the affected cells could be degraded (in the form of increased congestion), but this impact is below the maximum impact tolerated on the cellular voice networks. Furthermore, public safety's utilization during a localized-emergency only poses a risk to commercial subscribers if utilization due to commercial users is also high during this period (this would be the case if the emergency occurred during the busy-hour or because commercial utilization peaked as a result of the emergency occurring); if public safety roaming occurs when commercial utilization is low, there is limited impact on commercial subscribers. Overall, the risk of public safety roaming traffic significantly affecting commercial subscribers is not likely to be too high, but there is some risk of congestion during localized emergencies.

Additionally, Fig. 4 demonstrates that as more commercial spectrum is put into service for mobile broadband by networks that support roaming, the less of an impact public safety roaming would have on commercial subscribers (putting more spectrum into service is equivalent to additional commercial carriers allowing public safety users to roam onto their networks, and thus having access to the additional spectrum available on those networks). And it is likely that additional spectrum, beyond the roughly 60 MHz in use in 2010, will be available for mobile broadband in the near future. This spectrum will come in the form of additional spectrum already allocated being put into service, as well as additional spectrum being allocated to commercial carriers in the future.[13] With roaming agreements in place, spectrum allocations to commercial carriers indirectly benefits public safety; the more mobile broadband capacity commercial carriers have, the more public safety traffic those commercial networks can support for a fixed impact on commercial subscribers.

From a commercial carrier's perspective, the financial impact of having public safety users roam on their networks can be measured in terms of the effect on usage-based revenue and the effect on subscriber churn. With respect to the impact on usage-based revenue, allowing public safety users to roam can substantially increase this revenue. Indeed, commercial carriers could potentially benefit from a large windfall when large-scale disasters occur, assuming a usage-based pricing scheme (and while a flat-rate scheme eliminates the potential for windfall profits in these situations, it does not necessitate that the affected carriers experience a loss). And regardless of whether or not public safety traffic roams routinely or only during serious incidents, public safety traffic is unlikely to reduce usage-based revenue. In fact, it is only possible for public safety roaming to lower commercial usage-based revenue in two ways: (1) if commercial subscribers have usage-based pricing, public safety users have flat-rate pricing, and public safety traffic displaces the traffic of commercial users (e.g. through priority access); or (2) if public safety pays usage-based prices that are at much lower rates than commercial users pay, and public safety traffic displaces the traffic of commercial users. Overall, with respect to a

[13] Indeed, the FCC's National Broadband Plan indicated a goal to make an additional 300 MHz of spectrum available for broadband by 2015 (beyond the more than 500 MHz currently available).

commercial carrier's usage-based revenue, the benefits of having public safety roam on their networks are potentially high, and the risks are likely low.

As far as the risk of subscriber churn due to the presence of public safety traffic, several necessary conditions must be met for this to occur. First of all, the commercial carrier must have a roaming agreement with public safety and a competitor must not. Whether or not this condition is satisfied depends upon whether entering roaming agreements is voluntary on the part of commercial carriers or if it is mandatory (for instance, as a spectrum license requirement). For carriers that do enter into roaming agreements with public safety, subscribers churning away from a particular carrier due to the presence of public safety roaming traffic is only possible if: (1) the carrier's network experiences greater congestion as a result of public safety's roaming traffic, (2) a user must experience the effect of that congestion firsthand, recently enough to be memorable, and with large enough magnitude to bother him or her, and (3) users can discern that there is greater congestion and that he or she can attribute it to the presence of public safety traffic and not to other possible explanations.

The extent to which these conditions are satisfied may differ depending on the specific circumstances under which public safety traffic roams onto the commercial network (i.e. routine vs. localized emergency vs. large-scale wide-area disaster). With respect to public safety routine traffic, the likelihood of significant churn is small. This is because congestion due to routine public safety roaming is less likely to occur. Since commercial carriers can better anticipate the impact of routine usage on their networks (as opposed to the effect of an emergency response at an uncertain time, in an uncertain place, and of an uncertain magnitude), carriers can deploy additional infrastructure so as to reduce any congestion and thus capture both public safety and commercial usage revenue. With respect to public safety traffic during a large-scale disaster, Fig. 4 shows that the extent of the impact on commercial users is likely small, at least for the specific scenario studied. Therefore, since utilization in this scenario is low, the risk that commercial subscribers churn in response to a large-scale disaster along the lines of the scenario studied is not overly likely to be affected by the presence of public safety roaming traffic.

On the other hand, the impact of public safety roaming traffic on commercial subscribers during the localized-emergency scenario studied is about 5 times greater than the impact observed for the large-scale disaster scenario studied. Even though the impact is greater, it is unclear the extent to which commercial users will be able to perceive this effect. That is, during an emergency event, reduced performance for commercial users is likely to occur (perhaps even expected by subscribers) regardless of whether or not public safety's traffic is roaming and it's not certain that users will notice a dramatic difference with or without public safety users. Furthermore, in a localized incident, the number of commercial users affected by public safety roaming is likely to be relatively small given that the area affected by a localized incident is, by definition, small. Since the number of affected subscribers is low, the frequency of occurrence is rare, and the difficulties associated with perceiving the difference in service between commercial networks that allow public safety roaming and one that does not, the overall risk to commercial carriers due to subscriber churn from localized emergencies is not overly likely to be high. Thus, the overall risk of churn due to the presence of public safety roaming traffic is not likely to be very substantial.

5. Conclusions

Using the detailed cost model developed, this paper found significant benefits associated with roaming, and some risks, which can in part be mitigated by the choice of pricing scheme. From public safety's perspective, the primary financial benefit to priority roaming is the potential to reduce costs by paying for more roaming during periods of peak usage and deploying fewer cell sites dedicated to public safety users. Public safety agencies, when designing their networks, implicitly decide the worst-case scenario that can be supported. If the worst-case scenario prepared for would result in utilization levels over the entire multi-year lifetime of a cell site of less than 10%, this paper demonstrates that the net present value (NPV) of total costs can be decreased by paying for more roaming services (at commercial rates) and deploying less dedicated infrastructure. Thus, the more severe the worst-case scenario planned for, the greater the cost savings roaming capability provides. Additionally, this threshold utilization level also depends on both the cost of deploying a cell site and the price paid for roaming: as the cost to build and operate a cell site increases and/or progress in the commercial sector drives down roaming prices, the more cost-effective roaming becomes.

This paper also demonstrated that several of the potential risks associated with priority roaming can be mitigated by choice of pricing scheme. In particular, it was shown that a usage-based scheme has great advantages over a flat-rate scheme except when large-scale disasters occur that vastly exceed what was budgeted for, and that a hybrid scheme that uses usage-based pricing most of the time but caps costs during serious emergencies when predefined conditions are met (e.g. a state-of-emergency is declared) can leverage the advantages of both schemes.

A major advantage of flat-rate pricing is that it offers some cost certainty to public safety agencies. However, there are two major risks associated with a flat-rate scheme. The first is that flat–rate pricing provides limited incentive for public safety to make efficient use of commercial network capacity; this is a serious risk for commercial carriers. That is, with a flat-rate scheme public safety agencies have no reason to deploy dedicated cell sites beyond what's required to meet public safety coverage requirements or deploy technologies that will limit the amount of traffic that roams on commercial networks. For example, faced with a choice between deploying fixed video cameras that are wired or ones that are wireless (and roaming capable), flat-rate pricing gives public safety agencies no incentive to deploy the wired option, even if fixed video is not the best use of limited mobile broadband spectrum. Another risk, at least from the perspective of commercial carriers, is that flat-rate pricing could lead to commercial carriers losing usage-based revenue if public safety users displace a significant amount of traffic from commercial subscribers; this could affect the degree to which commercial carriers are willing to enter into roaming agreements with public safety.

Conversely, this paper demonstrated that usage-based pricing could mitigate both of these risks. For example, this paper demonstrated that usage-based pricing provides an incentive for public safety to deploy its own, dedicated cell site if its average utilization will be at least 10% over a 10-year period. Additionally, with a usage-based pricing scheme wherein public safety pays rates comparable to what commercial subscribers pay, it is impossible for carriers to lose usage-based revenue even if public safety displaces commercial traffic (in fact, commercial carriers may actually realize increased usage-based revenue from public safety users in this scenario).

However, a usage-based scheme can introduce other risks. In particular, the cost uncertainty associated with usage-based pricing could force government agencies whose budgets are set well in advance to ration public safety communications in harmful ways (i.e. rein in roaming usage, even if it's not socially optimal to do so). This paper demonstrated that if public safety users pay rates comparable to those paid by commercial subscribers, there is limited risk of rationing occurring during a serious localized emergency, but a greater risk during large-scale disasters. More specifically, it was shown that even for the worst-case localized emergency response modeled (such as a 'dirty-bomb' attack on NYC), roaming costs are on the order of a few hundred dollars per hour. In contrast, personnel costs associated with paying overtime to first responders involved in the emergency response are a couple of orders of magnitude greater than roaming costs. This means that not only are the roaming costs associated with the response to a localized-emergency small compared to public safety's budgets, these roaming costs are small even if only compared to the other costs associated with responding to a localized-emergency. In contrast, this paper demonstrated a scenario wherein a large-scale disaster response that lasted for 3 days could cost about $0.25 million. While rare, unexpected roaming costs at this level present a risk of harmful rationing; a risk that isn't present with flat-rate pricing.

Thus, in most scenarios, a usage-based pricing scheme is preferable; but at certain times a flat-rate pricing scheme is desirable. In addition, it is exactly those scenarios wherein a usage-based scheme is desirable (i.e. during routine use and localized-emergencies) that a flat-rate scheme is not; and vice versa. Since there is no reason why only one of these pricing schemes must be used exclusively, it may make sense to implement a hybrid approach that is a combination of the two. A hybrid scheme wherein usage-based pricing is employed as the default (i.e. for normal operation and during localized-emergencies) and a flat-fee invoked when a serious disaster occurs, would mitigate the potential harm from an usage-based pricing scheme (i.e. harmful rationing during large-scale disasters), while still preserving the incentives usage-based pricing provides during more routine use (and that flat-rate pricing wouldn't provide) and mitigating the risk of lost usage-based revenue for commercial carriers.

Finally, regardless of the pricing scheme, it was found that there is some risk that commercial users will experience a degraded level of service (in the form of increased congestion) due to public safety priority roaming, but that the degraded service is limited to a few, rare scenarios. For instance, if 60MHz is available for mobile broadband on commercial networks that have roaming agreements with public safety, adding all of public safety's traffic to the commercial network during the large-scale disaster studied in this work would only utilize 4% and 2% of the commercial capacity in the uplink and downlink of the affected sectors, respectively. This level of utilization is low, and is unlikely to significantly affect the congestion commercial subscribers experience (or the likelihood that they churn as a result). On the other hand, there's a greater risk that a commercial subscriber's experience will be degraded during a localized emergency response. This paper showed that if 60 MHz is available for mobile broadband, the sector utilization due to public safety roaming during the localized emergency scenario studied is about 20%. But this level of utilization is still below the level at which public safety priority access is capped on the cellular voice networks (i.e. 25%), and would be limited to only a handful of affected cell sites while the emergency response is going on (thus, the impact on commercial revenue due to subscriber churn in this scenario is not overly likely to be high). Moreover, the more carriers that form roaming agreements with public safety (and thus the more capacity that is available), the smaller the impact is on commercial users and the smaller the risk of subscriber churn is to commercial carriers because more competing carriers would be subject to the same conditions.

6. References

3G Americas. (2010). *Global 3G status UMTS / UMTS-HSPA/ HSPA+ / LTE.* Retrieved from http://www.3gamericas.org/documents/Global%20Status%20Update%20July%2027%202010.pdf

City of New York. (2010, February). *'700 MHz broadband public safety applications and spectrum requirements,' Comment before the Federal Communications Commission in the matter of implementing a broadband interoperable public safety network in the 700 MHz band (PS Docket No. 06-229).* Retrieved August 14, 2010, from http://fjallfoss.fcc.gov/ecfs/document/view?id=7020389715

FCC. (2008). *Second further notice of proposed rulemaking in the matter of implementing a nationwide, broadband, interoperable public safety network in the 700 MHz band (PS Docket No. 06-229).* Retrieved February 10, 2010, from http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-08-128A1.pdf

FCC. (2010a, March 16). *Connecting America: The national broadband plan.* Retrieved from http://www.broadband.gov/plan/

FCC. (2010b, October). *Mobile broadband: The benefits of additional spectrum (FCC staff technical paper).* Retrieved November 30, 2011, from http://download.broadband.gov/plan/fcc-staff-technical-paper-mobile-broadband-benefits-of-additional-spectrum.pdf

FCC. (2010c, May 12). *Order in the matter of requests for waiver of various petitioners to allow the establishment of 700 MHz interoperable public safety wireless broadband networks (PS Docket No. 06-229).* Retrieved from http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-10-79A1.pdf

FCC. (2010d, June). *Public safety nationwide interoperable broadband network: A new model for capacity, performance and cost (FCC white paper).* Retrieved August 14, 2010, from http://fcc.gov/pshs/docs/releases/DOC-298799A1.pdf

FCC. (2010e, May 20). *The fourteenth report in the matter of the annual report and analysis of competitive market conditions with respect to mobile wireless, including commercial mobile services (WT Docket No. 09-66).* Retrieved December 14, 2010, from http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-10-81A1.pdf

Hallahan, R., & Peha, J. M. (2008). *Quantifying the costs of a nationwide broadband public safety wireless network.* Paper presented at the 36th Telecommunications Policy Research Conference, Retrieved from http://www.ece.cmu.edu/~peha/costs_of_public_safety_network.pdf .

Hallahan, R., & Peha, J. M. (2009). *The business case of a nationwide wireless network that serves both public safety and commercial subscribers.* Paper presented at the 37th Telecommunications Policy Research Conference, Retreived from http://www.ece.cmu.edu/~peha/profitability_of_public_safety_network.pdf.

Hallahan, R., & Peha, J. M. (2010a). *Policies for public safety use of commercial wireless networks.* Paper presented at the 38th Telecommunications Policy Research Conference, Retrieved from http://www.ece.cmu.edu/~peha/public_safety_priority_access.pdf.

Hallahan, R., & Peha, J. M. (2010b). Quantifying the costs of a nationwide public safety wireless network. *Telecommunications Policy , 34* (4), 200-220.

Hallahan, R., & Peha, J. M. (2011). The business case of a network that serves both public safety and commercial subscribers. *Telecommunications Policy , 35* (3), 250-268.

Manner, J. A., Newman, S., & Peha, J. M. (2010). *The FCC plan for a public safety broadband wireless network.* Paper presented at the 38th Telecommunications Policy Research Conference, Retrieved from http://www.ece.cmu.edu/~peha/FCC_plan_for_public_safety.pdf.

Morgan Stanley. (2009, December 15). *The mobile internet report*. Retrieved December 12, 2010, from http://www.morganstanley.com/institutional/techresearch/pdfs/mobile_internet_report.pdf

National Commission on Terrorist Attacks Upon the United States. (2004). *The 9/11 commission report: Final report of the National Commission on Terrorist Attacks Upon the United States.* http://www.gpoaccess.gov/911/pdf/fullreport.pdf .

New York City Comptroller. (2010, July 28). *Comments on New York City's amended adopted budget for FY 2011 and the financial plan for FYs 2011 - 2014*. Retrieved January 23, 2011, from http://www.comptroller.nyc.gov/bureaus/bud/10reports/July2010_FY2011CommentsAmendedAdopted.pdf

New York City Independent Budget Office. (2006, March). *IBO's programmatic review of the 2007 preliminary budget: New York City police department (NYPD)*. Retrieved January 23, 2011, from http://www.ibo.nyc.ny.us/iboreports/agencyBudgets06/NYPD%20Program%20Budget_march06.pdf

New York City Office of Management and Budget. (2011a, May). *Agency budgets & projections: Fire department*. Retrieved May 7, 2011, from http://www.nyc.gov/html/omb/html/publications/projections.shtml?41

New York City Office of Management and Budget. (2011b, May). *Agency budgets & projections: Police department*. Retrieved May 7, 2011, from http://www.nyc.gov/html/omb/html/publications/projections.shtml?64

New York State Financial Control Board. (2010, July 22). *Review of FYs 2011 - 2014 financial plan (staff report)*. Retrieved January 23, 2011, from http://www.fcb.state.ny.us/pdf/FY2011_2014_Review.pdf

Peha, J. M. (2005). *How America's fragmented approach to public safety wastes spectrum and funding.* Paper presented at the 33rd Telecommunications Policy Research Conference, Retreived from http://web.si.umich.edu/tprc/papers/2005/438/Peha_Public_Safety_Communications_TPRC_2005.pdf.

Peha, J. M. (2006). *The need for fundamental reform in public safety spectrum and communications policy.* Working Paper #15, New America Foundation, Wireless Future Program, Retrieved from http://www.newamerica.net/files/WorkingPaper15_TVtoPublicSafety_Peha_FINAL.pdf.

Peha, J. M. (2007a). Fundamental reform in public safety communications policy. *Federal Communications Law Journal , 59* (3), 517-546. http://www.law.indiana.edu/fclj/pubs/v59/no3/9-Peha.pdf.

Peha, J. M. (2007b). How America's fragmented approach to public safety wastes money and spectrum. *Telecommunications Policy , 31* (10-11), 605-618.

Peha, J. M. (2008, May 26). *A 'successful' policy for public safety communications, Comment before the Federal Communications Commission in the matter of implementing a broadband interoperable public safety network in the 700 MHz band (PS Docket No. 06-229).* Retrieved from http://fjallfoss.fcc.gov/ecfs/document/view?id=6520011227

Spectrum Coalition for Public Safety. (2005). *Public safety spectrum: How much do we need for data?* Retrieved July 14, 2007, from http://www.spectrumcoalition.dc.gov/img/PS_Whitepaper_10-25-05.pdf

Tellabs. (2011, January). *Tellabs 'end of profit' study*. Retrieved Februrary 22, 2011, from http://www.tellabs.com/markets/tlab_end-of-profit_study.pdf

U.S. Department of Labor. (2008, July). *Fact sheet #17J: First responders and the part 541 exemptions under the Fair Labor Standards Act (FLSA)*. Retrieved January 23, 2011, from http://www.dol.gov/whd/regs/compliance/fairpay/fs17j_first_responders.htm

Verizon. (2011). *Verizon Wireless: Mobile broadband plans*. Retrieved April 15, 2011, from http://www.verizonwireless.com/b2c/mobilebroadband/?page=plans