The Feasibility of Utilizing the Cellular Infrastructure

For

Urban Wildlife Telemetry

By

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Abstract

Human populations inhabiting urban landscapes have increased from 224 million in 1900 to 2.9 billion in 1999. The wildlife biology profession utilizes telemetry derived location information for ecological and management studies that involve movement, behavior, habitat use, survival, productivity, and others. World-wide there were more than 1.2 billion cellular telephone users in 2003. A cellular phone based telemetry system is a feasible technology to assist wildlife biologists and researchers overcome the obstacles and requirements for conducting research in urbanized landscapes. A study was performed to assess functional and economic feasibility of developing a cellular-based telemetry system for urban wildlife use. A review of current literature that used traditional wildlife telemetry technologies resulted in the focus of four areas: the study of urban wildlife; traditional telemetry technologies; radio tag weights, frequency use, power, and cost of traditional telemetry technologies; and performance of traditional technologies in urban and non-urban landscapes. Geolocation by wireless communications systems is a relatively new market in the United States, and thus requirements and standards are still developing. Due to constraints outlined in this paper, at this time, the most feasible and promising approach to utilizing the cellular infrastructure for geolocation of urban wildlife is by establishing an ad hoc system for data transferal and accomplishing geolocation by ultra-wide band (UWB) technology.

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Introduction

Globally, human populations that inhabit urban landscapes have increased from 224 million in 1900 to 2.9 billion in 1999. Over the next 30 years, that population will increase by another 2 billion and comprise 60% of the world's total human population (Alberti et al. 2003, Traut and Hostetler 2003). Biological and physical properties of urban landscapes are redistributed by humans via such mechanisms as traffic congestion, sprawl, and air pollution. When integrated with other properties of the urban landscape, such as topography, social preferences, and urban infrastructure, a significantly different ecosystem emerges from these previously non-urban landscapes (Alberti et al. 2003). Anthropogenic activities have significantly altered the North American non-urban landscapes by fragmentation, loss, and altered disturbance regimes. The outcome from the transformation of non-urban to urban landscapes resembles that seen in the conversion from agricultural to urban use (Salsbury et al. 2004). Turner et al. (2004) submits that urban human populations live in a state of biological poverty. Urban landscapes are characterized by mosaic patterns, rigid disturbance regimes, exotic species introductions, extinctions, and reorganization of communities within the ecosystem. Due partly to these specific urban features, ecologists should be drawn to urban landscapes to test fundamentals of their discipline and solve problems (Rebele 1994).

Urban ecology is the nexus of social, biological, and economic sciences. Its understanding should be used to integrate social and biological information (Alberti et al. 2003). Due to the conversion of natural habitats to agriculture and urban landscapes, the examination of urban areas as habitat is necessary for effective species management (Salsbury et al. 2004, Traut et al. 2003). Alberti et al. (2003) present fundamental considerations for those studying urban ecology or attempting to determine resilience of urbanized landscapes, such as how does human activity and populations interact with individual, population, and community processes in an ecosystem?

Turner et al. (2004) concluded that it is possible to sustain a certain level of biodiversity in urban landscapes. Both inner urban and fringe ex-urban landscapes hold promise for biodiversity and biological interactions. However, our study of these features must increase significantly if we are to achieve compatible urban development. Although many urbanites generally are disinterested in ecology they likely understand that ecological features do exist within the urban environment. Those features that provide aesthetic appeal may be most valued (Manuel 2003). The study of wildlife in urban landscapes calls for re-evaluation of traditional techniques employed by biologists (Hegglin et al. 2004). Study of wildlife in urban landscapes promises to add to the sub-discipline and to broader ecology overall (Geggie and Fenton 1985).

Wildlife biologists use telemetry-derived location information for ecological and management studies of animal movement, behavior, habitat use, survival, and productivity assessments. Since the first functional telemetry system created by Cochran and Lord (1963), wildlife telemetry technologies have improved, especially with refinements to standard very high frequency (VHF) systems, development of satellite-based geographic positioning systems (GPS) and unique re-combinations of current systems. However, these improved technologies are hampered by physical and sociological restrictions of urban settings. Such as limited access to public or private lands, increased radio traffic and band-use, and dynamic attenuation patterns caused by changing topography and buildings. These restrictions make existing wildlife telemetry techniques and technologies more costly and less precise. Furthermore, public opposition to traditional methods used to study wildlife may impede progress of ecological understanding. Impediments to trapping, vandalism, limited access to privately owned lands, and limited spatial scales all demand a re-evaluation of wildlife study methods in the urban landscape (Quinn 1995).

Wildlife telemetry enables researchers to monitor individual animals in many varied terrains, environments, and states (Long and Weeks 1983). Millspaugh and Marzluff (2001) warn that ready availability and growing over-reliance on new telemetry systems should not distract biologists from obtaining actual observations of study animals.

Wildlife biologists conducting for urban wildlife research and management need new technologies and techniques that are better suited for urban settings and provide similar types of data. However, they also must generate statistically compatible data for comparison with other landscape types and use of historical data collected by traditional techniques.

Review of Literature

The review of current literature on studies that use traditional wildlife telemetry technologies focuses on four areas: the study of urban wildlife; traditional telemetry technologies; radio tag weights, frequency use, power, and cost of traditional telemetry technologies; and performance of traditional technologies in urban and non-urban landscapes.

Study of Urban Wildlife

Bourassa (United States Department of Agriculture, Animal and Plant Health Inspection Service, person. commun.) has witnessed an increase in the number of studies that investigate wildlife in urban landscapes. Coleman et al. (2002) stated that it is necessary to study the effects of urbanization on wildlife; including fragmentation, development density, and increasing human activity. As examples of existing unmet needs, Chamberland and Leopold (2002) expressed a need to describe social structure of urban raccoon (*Procyon lotor*) populations, whereas McClennen et al. (2001) noticed a lack of studies that examine relationships between human disturbance and coyote (*Canis latrans*) behavior.

Recent studies of urban wildlife noted that some features of an urban landscape actually may benefit wildlife. Dykstra et al. (2001) suggests that red-shouldered hawks (*Buteo lineatus*) may benefit from the presence of some features (anthropogenic ponds, bird feeders) in a suburban landscape. Similarly, Estes and Mannan (2003) found that urban landscapes often provided an increasingly abundant and available prey base for hawks more so than did neighboring rural landscapes. Information from recent urban wildlife studies is having direct implications to management of landscapes along the rural-urban gradient. For example, Atwood et al. (2004) concluded that travel corridors and forage habitat are necessary for coyotes to successfully occupy landscapes that display high human activity.

Traditional Telemetry Technologies

Traditional telemetry technologies used to study wildlife include Very High Frequency (VHF), Global Positioning System (GPS), satellite, Global Location Sensor (GLS), and hyperbolic systems. Table 1, as assembled by Mech and Barber (2002), compares the three most common technologies used by wildlife biologists. The original, and still most widely used, wildlife telemetry method uses of very high frequency telemetry and human operators of equipment. Low frequency radio waves tend to travel farther than do higher frequency waves and are less affected by reflection off vegetation and topography, but they require longer antennas to accommodate the longer wavelengths (Mech and Barber 2002, Kenward 2001). Another derivation of this type of telemetry system is automated very high frequency radio tracking, which can be prone to problems (Kenward 2001). Some automated very high frequency systems provide suitable area coverage and low positional error, but they tend to be very expensive (Samuel and Fuller 1996). Others are suitable only for small areas and thus are limited to use in studies involving small animals (Briner et al. 2003). Based on his 30-year experience with traditional analog telemetrys, Bourassa (USDA APHIS, person. commun.) believes that automated analog telemetry systems have been largely unsuccessful primarily because the base station's range is much more limited than the human operator's range. Human operators can distinguish a signal within background noise up to -150 dbm, whereas an analog automatic base station can recognize intelligent signals in the range of -100 to -120 dbm. Other automated systems that may not work in the very high frequency range include satellite radio tracking systems, global positioning systems, and data-storage tags. Some systems may even combine approaches (Kenward 2001).

The use of global positioning system as the method of tracking is becoming more common with wildlife studies. This technology uses a time of arrival algorithm to triangulate an animal's location from signals emitted by satellites orbiting the earth (Kenward 2001). Today, Differential Global Positioning System (DGPS) has now replaced the original GPS applications almost completely, even though the original acronym can be used interchangeably (Mech and Barber 2002)

Satellite telemetry, a relatively new approach in wildlife telemetry, transmits an ultra high frequency signal to orbiting satellites that receive the signal and then use the

Table 1. Characteristics of Very High Frequency (VHF), Satellite, and Global Positioning System (GPS) Collar Telemetry[1].

Characteristics	**VHF**	**Satellite**	**GPS Collar**
Collar Weight[2]	560 g	520 g	830-920 g
Initial investment per collar	$300	$3,000	$3,000
Cost per 100 locations	High	Medium	Low
Data retrieval potential	High	High	Low to high depending on likelihood of dispersal
Accuracy	Medium to high depending on effort	(+/-500 m)	High; usually accurate to 20 meters
Longevity	< or = 6 years	1-12 months depending on cycling	3 weeks-10 months depending on interval between location attempts
Interference from weather	High (aerial telemetry)	None	None
Interference from habitat	Low	High	High
Interference from topography	Medium	High	High
Intrusiveness after collaring	high	none	None to high[3]

[1] Adapted from Merrill (2002);
[2] Collar weight varies by species and collar manufacturer, weights given are for wolves;
[3] Depends on frequency of data downloading.
* Retrieved from Mech and Barber (2002).

Doppler Effect to fix the location of that transmitter on the ground. The location information is then transmitted to a receiving and interpreting service such as ARGOS (Mech and Barber 2002). Satellite telemetry transmits within the ultra high frequency range (401.650 MHz) and radiates output at 250 milliwatts to 2 watts, whereas VHF systems radiate at 10 milliwatts (Mech and Barber 2002).

The Global Location Sensor is a relatively unknown and not commonly used system that determines a position on the earth using ambient light and time of day. The system provides two estimations every 24 hours, is inexpensive, but has very large positional error (150 kilometers) (Mech and Barber 2002).

Hyperbolic systems are automated systems that measure time differences in signal transmissions. Millspaugh and Marzluff (2001) theorize that hyperbolic systems may be the next wave of telemetry technology that provides significant advancement.

Radio Tag Weights, Frequency Use, Power, and Cost of Traditional Telemetry Technologies

Commercially available transmitters range in weight from 350 milligrams (Kenward 2001) to 400 grams and more (Samuel and Fuller 1996). Global positioning system transmitters generally weigh 100 grams or less; some prototypes weigh as little as 33 grams (Kenward 2001). Transmitter weight should not exceed 5% of the animal's body mass (Kenward 2001), and researchers who abide by this protocol report few negative effects on their telemetered subjects (Agren et al. 2000, Fitzgerald et al. 2003, Whitaker and Shine 2002, Briner et al. 2003). Although, some researchers have exceeded this guideline due to special circumstances (e.g., Andersen et al. 2000). Kenward (2001) notes that transmitter mass should be kept well below the recommended standard whenever possible. He further suggests limiting that transmitter weight to 2-3% of body mass in studies that involve bats and birds, both of which rely on lift for escape and survival.

Phillips et al. (2003) warn that even the smallest of satellite transmitters may negatively affect the behavior of certain pelagic bird species. Additionally, they reported a very high mortality rate associated with use of implantable satellite transmitters. Krausman et al. (2004), in a recent report on negative effects of certain global positioning system radio collars, found that the combination of size, localized weight, collar inflexibility, and shape produced lesions on large mammals. In contrast, Durnin et al. (2004) found little evidence of negative effects from radio collars on endangered large mammals.

In the United States, access to and use of radio frequencies are regulated by the Federal Communication Commission, in part to assure that conflict among users can be avoided (Mech and Barber 2002). Very high frequency tracking systems most commonly are assigned to the 148-152, 163-165, and 216-220 megahertz ranges and usually are separated by about 10 kilohertz to prevent overlap and compensate for signal drift (Mech and Barber 2002). Automated very high frequency systems generally are insensitive to weak transmissions from small transmitters or can not adequately cover the entire range of larger animals outfitted with strong signal transmitters (Kenward 2001). For example, Samuel and Fuller (1996) described an automated tracking system that emitted an 8-20 watt signal and provided reception over 3,000 hectares.

Power for traditional wildlife telemetry methods has been supplied via batteries that range from very small to large (see Table 2). Newer technologies often require more power than traditional very high frequency methods. For example, satellite telemetry transmitters typically are powered by 3 "D-size" lithium batteries (depending on transmitter cycling), which last from 3-12 months (Mech and Barber 2002). Most researchers today view power supply as the primary factor that limits use of telemetry technologies (Bourassa, USDA/APHIS, person. commun.).

Solar cells paired with capacitors or a combination of capacitor and rechargeable nickel-cadmium batteries (for high-powered signal generation) have been incorporated into telemetry units. However, improved efficiency and management of power supplies through the use of microcontrollers have replaced most use of solar cells (Fuller et al. *in press*).

Costs associated with traditional wildlife telemetry applications include equipment, personnel salaries and expenses, and transportation, all of which will be influenced by the number of telemetered animals, the frequency of equipment cycling and location determinations, and difficulty of obtaining locations. In some cases, costs for data compilation, analysis, report writing, and publication are added (Samuel and

Table 2. Dimension, voltage, capacity and life expectancy at typical working currents of commonly used power cells in wildlife radio tags (retrieved from Kenward 2001).

Silver button												
Type	**Weight (g)**	**Cap (mAd)**	**Diam (mm)**	**Height (mm)**	**Cap (mAh)**	**Voltage**	**Cap (Wh)**	**Vol (mL)**	**W h g^{-1}**	**W h ml^{-1}**	**life at at 0.03 mA**	**life at at 0.07 mA**
Ag335	0.14	0.21	5.8	1.25	5.04	1.5	0.007	0.035	0.049	0.199	7 day	3 day
Ag317	0.19	0.48	5.8	1.65	11.52	1.5	0.017	0.047	0.089	0.361	16 day	7 day
Ag364	0.3	0.79	6.8	2.2	18.96	1.5	0.028	0.086	0.093	0.325	26 day	11 day
Ag397	0.51	1.54	7.9	2.7	36.96	1.5	0.055	0.143	0.107	0.384	51 day	22 day
Ag392	0.57	1.79	7.9	3.6	42.96	1.5	0.064	0.191	0.112	0.335	60 day	26 day
Ag393	1.13	2.9	7.9	5.35	69.6	1.5	0.104	0.284	0.092	0.366	3.0 mo.	41 day
Ag386	1.7	5	11.6	4.3	120	1.5	0.18	0.493	0.105	0.365	5.4 mo.	2.3 mo.
Ag357	2.27	7.3	11.6	5.35	175.2	1.5	0.262	0.614	0.115	0.426	7.8 mo.	3.4 mo.
Lithium button												
BR2032	2.5	7.9	20	3.2	189.6	3	0.568	1.092	0.227	0.52	6.6 mo.	25 day
Lithium spool												
10-25	5.5	20.8	10	25	499.2	3.6	1.797	2.133	0.326	0.842	1.4 yr.	3.2 mo.
1/2AA	8.6	37.5	15	26	900	3.6	3.24	4.992	0.376	0.649	2.5 yr.	5.5 mo.
AA	21	87.5	15	52	2100	3.6	7.56	9.985	0.36	0.757	6 yr.	1.1 yr.
C	56	219	26	53	5256	3.6	18.921	30.579	0.337	0.618	>10 yr.?	2.7 yr.
D	115	583	35	62	13992	3.6	50.371	64.823	0.438	0.777	>10 yr.?	7.3 yr.

Fuller 1996). Long and Weeks (1983) recommend that cost effectiveness of telemetry technologies should be based solely on the cost per number of locations obtained.

Research projects that involve wildlife telemetry usually are limited more by economic concerns than by experimental design or ecologic or scientific constraints (Millspaugh and Marzluff 2001). Radio tags that store data, like some global positioning system tags, also must incorporate the means to radio-relay data to a receiver or the tag must be recovered physically for downloading. Because automated very high frequency location systems are generally expensive to develop, human-operated telemetry systems still are most efficient. However, recent advances in digital signal processing give great promise to automated systems (Kenward 2001).

Access to and use of certain technologies often comes at a high price. For example, use of satellite telemetry requires a $90-$260 monthly access fee per individual and transmitters costs $3,000-$4,500 each (Mech and Barber 2002). In contrast, global location sensor systems generally are inexpensive, in that each transmitter costs about $200 (Mech and Barber 2002). Global positioning system radio tags average about $4,000 each (Kenward 2001). Installation of an automated very high frequency tracking systems receiving station runs about $50,000 (Samuel and Fuller 1996), whereas traditional very high frequency transmitters cost from $100-$300 and receivers $800 to $4,000 (Fuller et al. *in press*).

Performance of Traditional Technologies in Urban and Non-urban Landscapes

Studies of wildlife in urban landscapes have revealed serious limitations in our ability to use traditional wildlife telemetry sampling technologies. Citing the short range of the very high frequency equipment in urban landscapes, Geggie and Fenton (1985) were able to provide only limited conclusions regarding use of urban habitats by bats. Additionally, with the increased use of sensors in wildlife telemetry, variability in sensor performance must be addressed (McClennen et al. 2001).

Under certain conditions, traditional telemetry technologies can provide suitable levels of accuracy in urban landscapes. While studying urban coyotes using traditional very high frequency equipment, Quinn (1995) attained an error polygon of approximately 1.307 hectares, but only when locations were recorded within 400 meters of the animal.

Similarly, Coman et al. (1991), while studying red foxes (*Vulpes vulpes*), attained + or – 2 degrees of bearing error. In their study of urban bats, Greggie and Fenton (1985) noted that marked individuals were detectable only when they were within 800 meters of the receiver. However, other studies indicate greater performance of traditional telemetry technologies in urban landscapes. Along an urban – suburban – rural gradient, Prange et al. (2004) established mean error polygons of approximately 0.66, 0.45, and 1.14 hectares at 3.5, 3.2, and 2.9 degrees respectively when they were within 47 meters of test collars.

Telemetry performance in non-urban landscapes varies depending on the technology employed. Very high frequency transmitters usually provide a 5-10 kilometer range on the ground and 15 to 25 kilometers aerially. This range can be extended somewhat by using low frequency signals, which are less affected by reflection than those in higher frequencies, but low frequency signals require a longer antenna to propagate and receive the signal. The global location sensor system achieves a 150-kilometer positional accuracy. Good quality Differential GPS units are accurate to within ~5 meters. Satellite telemetry locations are categorized into four classes, with the most precise providing at least 150 meters positional accuracy (Mech and Barber 2002). Global positioning system accuracy with post differential correction provides a resolution of 20 to 30 meters (Kenward 2001). Automated tracking systems that use VHF frequencies have achieved a positional accuracy of 40 meters within a 3,000-hectare area when tracking large mammals (Bookhout 1996). Using traditional very high frequency equipment powered by 2,000 and 1,600 mAh lithium batteries, Agren et al. (2000) recorded signals that exceeded a 100-meter range and that lasted for five months. In their study of swift foxes (*Vulpes velox*), Kamler et al. (2003) attained an accuracy of 84 meters (95% being <145 meters) using traditional very high frequency equipment. Briner et al. (2003) tested an automatic very high frequency tracking system on small mammals and obtained an acquired accuracy of 0.13-2.58 meters. Nelson et al. (2004) obtained positional accuracy of <100 meters and error polygons of <4 hectares when studying deer outfitted with global positioning system radiocollars. Using satellite telemetry, Haines et al. (2003) used a single less than or equal to 1,000 meter error polygon to map migration pathways of birds.

A general lack of strong conclusions towards animal interaction with urbanized landscapes can be witnessed in the extant literature. Employed tools were, generally, unable to provide conclusive results from which researchers could interpret and infer with strong confidence. Additionally, gaps existed regarding habitat use and resource selection, effects of human behavior on animal behavior, movement and landscape variables across ecotypes.

The shortfalls in performance of existing telemetry technologies in urban landscapes creates a need for research and development into systems that are better able to provide precise data and conclusive results. World-wide, greater than 1.2 billion people used a cellular telephone in 2003 (Schiller and Voisard 2004). These 1.2 billion cell phone users are supported by a vast infrastructure of optimally placed antennas, routers, and transmitters to produce the United States' cellular telecommunications network. The network is a logical beginning for developing a wildlife telemetry system designed specifically for use in urbanized landscapes. This paper attempts to test the previously assumption by determining if a cellular phone based telemetry system is a feasible technology to assist wildlife biologists and researchers overcome the obstacles and requirements for conducting research in this landscape and newly acknowledged habitat type.

Materials and Methods

To determine the functional feasibility of a technology for wildlife telemetry use, one must first understand the basic methods, requirements, and issues of how location is determined. Also, knowledge of the infrastructure (i.e., hardware, software, frequencies of the cellular networks and wireless communication) is necessary. Finally, knowledge of the wireless telecommunications markets and future directions of the marketplace is necessary in determining a technologies' economic feasibility.

To assess the functional and economic feasibility for developing a cellular-based telemetry system for urban wildlife use, I first identified and defined the different methods used by cell-phone and wildlife telemetry industries to provide location-based information. Each method was analyzed for accuracy, cost (both the data collecting service and hardware), ease use for end-users attempting to retrieve usable data, weight and size requirements of transmitters and potential uses and limitations. In addition to these currently available commercial methods, I also briefly assessed the economic feasibility of a prototype very high frequency telemetry array affixed to cell phone towers.

To assess the economic feasibility of the cellular network's utilization, three cell-phone service providers and three American-based wildlife telemetry companies were surveyed. Cell-phone providers were asked what location-based services and technologies currently are provided and whether they would be willing to provide specialized location-based services for wildlife telemetry if the technology proves feasible. Wildlife telemetry companies also were asked what location-based services and technologies they provide.

I also conducted a literature review to identify the telemetry technologies currently used by field wildlife biologists. I used this information to validate and contrast with results from my survey of commercial providers.

Results

Based on the surveys and literature review, the following six subject areas of cellular telecommunications were assessed to determine if the network is a feasible approach to the development of an urban wildlife telemetry system. The methods used to gain these results were modified while conducting the study to accommodate unforeseen difficulties.

Changes were made to the methods while conducting this study. Methods to the industry surveys were modified to accommodate a lack of either cooperation or feedback, or limited ability to discuss the technical aspects of the subject matter at an interdisciplinary conceptual level. Originally three United States based companies from each discipline (wildlife telemetry and cellular telecommunications) were intended to be surveyed. Of the four wildlife telemetry companies contacted only one replied, and the company was only able to discuss the technical aspects of its existing commercially offered telemetry systems. The five cellular telecommunications companies and one industry association that were contacted resulted in only one company willing to cooperate with very limited feedback. To compensate for the low response, subject matter experts were identified from the literature and personal communications. These alternate industry representatives were either members of academia from their respective discipline or specialized researchers with a public agency. The observed results from these modifications are not significantly different from what was expected with the original methodology.

Geolocation

Currently, there are three ways to perform geolocation: triangulation, trilateration, and traversing. Triangulation is the geolocation method used most commonly in wildlife telemetry and it measures the angle from which a signal radiates from at least two locations. Trilateration employs multiple base stations and establishes distance from a radiated signal to each base station, where the intersection of these radii thus establishes an error polygon. Finally, traversing combines these two techniques and uses distance-angle pairs to determine location (Schiller and Voisard 2004). There are two ways to accomplish each of these techniques: self-positioning and remote-positioning. With self-positioning, geolocation calculations are conducted at the mobile terminal site, whereas with remote-positioning, calculations are conducted at the base stations or a third party locations (i.e., Internet server or researcher computer) (Caffery 2000).

There are five basic techniques that are suitable for use with wildlife telemetry geolocation. They are cell of origin, time of arrival, angle of arrival, signal strength measurement, and location pattern matching.

Cell of origin determines a mobile terminal's location by determining from which cell, or area of radio coverage for one base station, a signal is being radiated by observing which base station received a transmission. Table 3 provides a short comparative of positioning systems.

The concept of time of arrival actually can be applied using any one of three different methods: time of arrival, and time difference of arrival (TDOA), or enhanced observed time difference (E-OTD). These methods all assume a constant signal travel speed and, using that constant, calculate the distance between the point of origin and the destination by measuring the time differential of the signal as it was received at a base station. Enhanced observed time difference is a mobile terminal-based positioning technique, where as time difference of arrival positioning occurs at a base station or a third party location (i.e., server or researcher's computer). If enhanced observed time difference techniques are to work, base station signal emissions must be synchronized from known points, which easily can be achieved by affixing global positioning system receivers to each base station. Fifty meter accuracy is expected using this method of geolocation and third generation systems are expected to produce even better accuracy. The enhanced observed time difference method has the advantage of being used indoors. Ericsson and Cambridge Positioning currently provide solutions using this technique (Jagoe 2003). Global positioning system, which uses a time of arrival geolocation technique, may be difficult to consistently achieve line of sight with four GPS satellites, a minimum accepted standard today (Schiller and Voisard 2004).

Table 3. Characteristics of currently available positioning systems as adapted from Schiller and Voisard (2004).

Name	**Category**	**Tracking/ Positioning**	**Mechanism**	**Medium**	**Precision**
Global Positioning System (GPS)	Satellite	Positioning	Time of Arrival (TOA)	Radio	25 m
Diffential Global Positioning System (DGPS)	Satellite	Positioning	Time of Arrival (TOA)	Radio	3 m
Wide Area Augmentation System (WAAS)	Satellite	Positioning	Time of Arrival (TOA)	Radio	3 m
Radio Frequency Identification (RFID)	Indoor	Tracking	Cell of Origin (COO)	Radio	Cell
Global System for Mobile Communications (GSM)	Network	Both	Cell of Origin (COO), Angle of Arrival (AOA), Time of Arrival (TOA)	Radio	Cell, distance in 555 m steps
Mobile Positioning System (MPS)	Network	Both	Cell of Origin (COO), Angle of Arrival (AOA), Time of Arrival (TOA)	Radio	150 m
Nibble	Network	Positioning	Signal Strength	Radio	3 m

Angle of arrival (AOA) uses fixed direction antennas to triangulate the location from which a signal was radiated. Some private companies offer commercially available solutions using angle of arrival and time difference of arrival for geolocation determination. A disadvantage, however, to both angle of arrival and time difference of arrival is base station modification necessary to accommodate both geolocation methods by either accurately measuring signal arrival time or angle. Additionally, if time difference of arrival is to be effective, the mobile terminal's transmission must be received by at least three base stations (Jagoe 2003).

Signal strength measurement assumes that the strength of a signal degrades at a constant rate. Using this known degradation factor, a spatial distance can be determined by assessing differences between initial and received strength of signal. There are free versions of this system available that use a signal strength measurement geolocation technique over a Wireless Local Area Network (WLAN) system to locate laptop computers (Schiller and Voisard 2004).

Finally, location pattern matching compares received signals against a database of radio frequency patterns and multi-path characteristics and then selects the most probable location. The location pattern matching technique of geolocation is patented by U.S. Wireless Corporation. It achieves FCC E911 accuracy requirements of 100 meter accuracy 67% of the time and 300 meter 95%. It is suited particularly to urban landscapes because line of site is not a requirement (Jagoe 2003).

One can increase accuracy of geolocation by combining elements of these 5 techniques. For instance, cell of origin only approximates position of a mobile participant and can be rather imprecise. However, if cell of origin is combined with angle of arrival, precision increases because the antennas used in angle of arrival divide the 360 degree receiving arc into defined segments. If a time of arrival analysis is added, which will allocate time slots for location determination into steps of approximately 555m, the precision can be increased even further. Finally, if at least four base stations are able to receive and calculate the previously mentioned calculations then an Uplink Time of Arrival (UL-TOA) method is achieved. This final method has a precision of 50 to 150 meters (Schiller and Voisard 2004).

Issues of Telephony

To avoid the trunking effect, where a large number of users are limited to using a small set of radio frequency channels, of digital cellular networks in the United States, a telecommunications system employs one of three different access approaches: time division multiple access (TDMA), code division multiple access (CDMA), or frequency division multiple access (FDMA). Time difference multiple access allows access of one mobile terminal at a time via the allocation of a time slot. Code division multiple access uses what is called a unique pseudonoise spreading code assigned to each signal. Frequency division multiple access allocates separate frequencies per transmission. A subset of the frequency division multiple access approach is space division multiple access (SDMA) (Schiller and Voisard 2004). These approaches increase the complexity of the cellular network as a technology for wildlife telemetry. In the United States code division multiple access is the preferred digital network choice because it mitigates multipath fading and multiple user interference affects, has low power transmission, high load capacity, and has the ability to use universal frequencies. With the code division multiple access and time division multiple access networks, time of arrival and time difference of arrival techniques are possible via remote- or self-positioning. Both code division and time division multiple access-based cellular systems can be enabled for time of arrival and time difference of arrival geolocation techniques. Additionally, Global System for Mobile Communications (GSM), the primary digital cellular network in Europe and Asia, allows for the same calculations (Caffery 2000).

The first generation North American analog communication system (AMPS) is unable to provide geolocation via remote-positioning (Caffery 2000). Thus, all geolocation through AMPS must be conducted via self-positioning.

Sources of Error in Geolocation

Multipath, no-line of sight (NLOS), or attenuation propagation is a primary factor in geolocation error. This error propagator occurs where a radiated signal deflects off physical objects (e.g., mountains, buildings) and can affect time- and angle-based, and signal strength geolocation techniques. Another type of error propagator is multipath fading, or fast fading. Multipath fading is similar to multipath propagation in that multiple received signals have different phase, delay, and amplitude. Shadowing, also known as slow fading and shadow fading, is another type of error that can occur in telecommunications-based geolocation. It is the variation within a frequency of a radiated signal over distance depending on the signal's wavelength. Similar to shadowing, path loss is the natural degradation of signal power over distance. The accuracy of geolocation techniques angle of arrival, time of arrival, and time difference of arrival are affected by multipath error propagation (Caffery 2000). Each geolocation technique is affected differently by each type of introduced error and some even rely on error for position determination. For example, path loss may decrease the ability of a time of arrival technique, but is the exact variable calculated to determine position by signal strength measurements.

Infrastructure for Geolocation using Wireless Communications

With infrastructure-based systems, wireless, wired, and hybrid systems are possible. A mobile terminal, or radio tag, transmits and/or receives with a base station (e.g., cellular tower). If a base station receives a transmission, it relays the signal to the appropriate destination via a wired system. It is possible to combine wireless and wired systems to create an ad-hoc or multihop system. In this case, a wireless system might be used to transmit location data from an animal's radio tag to a base station, which then sends the data via traditional phone line to a researcher's website or server (Schiller and Voisard 2004).

The main differences between the cellular network system and a wireless local area network are the consistency of the equipment used in the WLAN system and the systematic placement of cellular network base stations. The frequencies that the wireless local area network system occupies (2.4 to 5 GHz range) make up part of the Industrial, Scientific, and Medical band (ISM) which is not regulated nearly as strictly as that of the cellular network frequencies (Schiller and Voisard 2004). Wireless Fidelity (WI-FI) and the new extended range WLAN (WI-MAX) systems are types of wireless local area network systems.

The fundamental issues and tradeoffs associated with determining a mobile terminal's location using radio communication equipment are the same whether for studies that use traditional very high frequency telemetry equipment or those that use the cellular network. Data rate and transmitter cycling, distance and animal range, and transmission power all must be considered. Coping with these tradeoffs has resulted in two different technological approaches: cellular, wide-area network systems and wireless local area network systems based on the internet. The cellular system excels for long-range uses where as the wireless local area network system is better for short to medium range purposes (Schiller and Voisard 2004). However, the WI-MAX system promises to be relatively low power with a range of about 30 miles (Reed 2004). The Universal Mobile Telecommunications System (UMTS) likely will be the next generation of telecommunications because it integrates aspects of both the cellular network and wireless local area network systems to include base station interconnection and global system for mobile communications and transmission control protocol/internet protocol (TCP/IP) type network integration (Schiller and Voisard 2004). If we are to accommodate the third generation of wireless technologies, many requirements must be met, including increased bandwidth, standardized and vast infrastructure, and management of the infrastructure (Evans 2003).

Wireless Telecommunications Frequencies

The suitability of mobile communications as a telemetry option is constrained because its frequencies are limited in the amount of data they can transmit and its effectiveness in dealing with error caused by multipath. Mobile communications operate within the 800 MHz to 5 GHz band. Frequencies above this range do not penetrate walls well and below this range do not have enough data capacity in the bandwidth. The 900-1800 MHz range typically is reserved for large-scale outdoor systems, whereas the 2.4-5 GHz band generally is used or short-scale indoor systems such as wireless local area network that allow wireless computer communication (Schiller and Voisard 2004). When transferring data via radio waves, connections may degrade when the mobile terminal is in motion. In such cases, data transmission should be limited to times when a mobile terminal is not in motion or slowly moving, or use general packet radio service (GPRS) that transmits data similar to the Internet (Stehr 2003).

Wildlife Telemetry as a Location Based Service

Location-based services (LBS) is an industry term for geographically aware services provided to cellular subscribers. An example of a location based service is Enhanced 911 services (E911). Telematics is the transfer of data via telecommunications networks and is gaining increasing importance because of recent technological developments (Evans 2003). An example of telematics is mobile computing via wireless local area network. To create a location based service the many complex technologies need to be integrated (Jagoe 2003). A comparison of requirements for non-wildlife telemetry location based services can be seen in Table 4.

From the point of view of wildlife telemetry, location based services must be considered device-oriented application with services that are external to the point(s) of interest. Current examples of this include a car or a fleet of cars. It would also be considered a pull-type service meaning that a user (researcher) would pull the location information from the service. Finally, the location based service model applied to wildlife telemetry primarily would provide a passive service. Existing passive-type services include fleet management, such as is used by United Parcel Service (UPS) or other shipping and distribution companies (Schiller and Voisard 2004).

Middleware likely would be required to develop wildlife telemetry as a location based service. Middleware is the application or set of applications that facilitates and integrates different databases, data types, and applications likely found within the system. In this case, integration might involve position information derived from a particular geolocation approach being, either translated to a useable and familiar data format for biologists or with other datasets of interest to the researcher (e.g.., topography, wetland, or soils datasets) (Schiller and Voisard 2004).

Figure 1 illustrates how a location based service model might be applied to urban wildlife telemetry. The mobile terminal transmits a signal that is received by base stations and is sent to a location position provider. The location position provider either

Table 4. Requirements of common location-based service applications, as adapted from Jagoe (2003).

Application	**Entry-Level Accuracy Requirements**	**Mass Acceptance Accuracy Requirements**	**Custom Device Required?**	**Objective**	**Location Frequency**
Location-sensitive billing	Cell/Sector	250 m	No	Competitive pricing	Originated calls, received calls, midcall
Roadside assistance	500 m	125 m	No	Send help	Originated calls
Mobile yellow pages	Cell/Sector	250 m	No	What's near me?	Originated calls
Traffic information	Cell/Sector	Cell/Sector	No	What's traffic like?	Originated calls or every 5 minutes
Location-based messages	Cell/Sector	125 m	Short message or data capable	Advertise, alert, inform	Originated calls or every 5 minutes
Fleet tracking	Cell/Sector	30-125 m	No	Resource management	Every 5 minutes or on demand
Track packages	Cell/Sector	Cell/Sector	Yes	Locate and direct	On demand
Driving directions	125 m	30 m	Yes	Guidance	Every 5 seconds

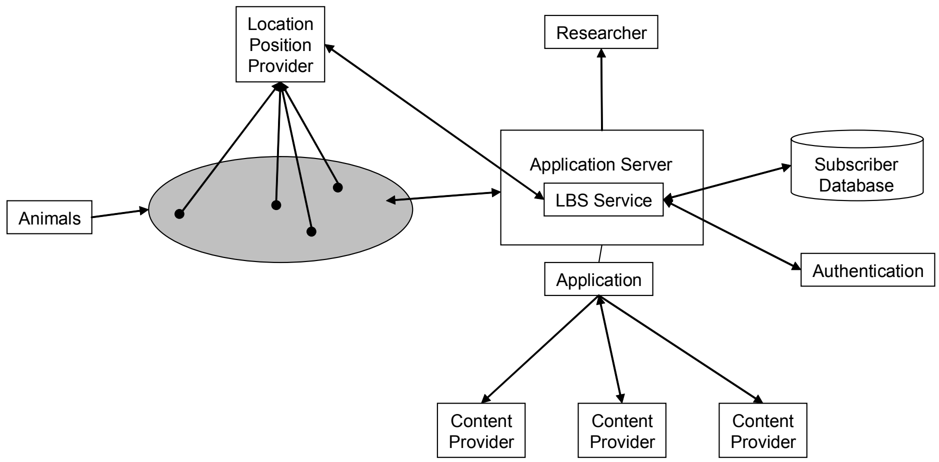

Figure 1. Wildlife telemetry LBS architecture, as adapted from Schiller and Voisard (2004).

conducts the geolocation calculations or converts already calculated locations into a useable data format. This is sent to the application server that houses the wildlife telemetry location based service. The wildlife telemetry location based service confirms the mobile terminal is a subscriber; selects any additional geographic data requested by the researcher; and packages the dataset to be retrieved or delivered to the researcher.

Discussion

The primary commercially available technologies used for wildlife telemetry in urbanized landscapes are the traditional manually operated very high frequency and global positioning systems. Both of these technologies are limited in the quality of data they can produce. Manually operated very high frequency systems are severely constrained in urbanized landscapes by operator access to private property, achieved accuracy, and range of the system. Global positioning system radio-tags are not limited by access to private property or range but by achieved accuracy (~25 meters) and hardware cost. Both of these commercially available technologies provided limited conclusive results from the available literature. Failures to gain conclusive results from applying existing telemetry technologies to the study of urban ecology may help explain the lack of existing research and slow the expansion of the discipline.

Constraints to telemetry technologies are especially apparent in urbanized landscapes as opposed to conducting research in more natural settings. Research in more natural settings tends to be conducted where property access is not a limiting factor to data acquisition. Also, radio frequencies are not subjected to the same intensity of multipath propagators as is seen in urbanized landscapes. Telemetry constraints and limitations of urban landscapes either decrease the achieved accuracy level or prevent the systems from completely functioning. Finally, as witnessed by the number of studies, most research money is allocated for study in more natural settings. Thus, hardware and operation costs become even more limiting for conducting urban telemetry studies.

Limited access to private property found in urbanized landscapes is a primary constraint to conducting research using human operated telemetry equipment. The most efficient way to compensate for this constraint is to eliminate the need for access to private lands. An automated system is ideal for urban landscapes. An automated system significantly decreases the personnel costs that are associated with human operated systems. One negative aspect of automated telemetry systems is the lack of actual observation of study individuals. Data collected through automated systems should never replace actual observation of animal behavior. Actual observation should be considered a requirement when designing a study that involves the use of radio telemetry to provide a control, ground truth, and a sense for collected telemetry data interpretation.

Utilizing the cellular telecommunications network as a telematics platform is less costly than human operators or satellite data transfer services for GPS such as ARGOS. Telematics services via cellular network are already commercially available with both cost and efficiency expected to improve over time. However, using the cellular network for data transfer does not address the issue of geolocation, just the transfer of data from field to office.

Future wireless communication technologies promise to integrate the properties of both cellular and wireless local area networks (Schiller and Voisard 2004). Data connections, on the other hand, will likely come in two forms. In order to accommodate large volume data transfers, batch- or packet-type systems occupying high bandwidths are likely to develop. The other form will accommodate continual connections that will be used for smaller data volume purposes (Evans 2003).

A major market driver of geolocation services via the cellular network in the United States is the E911 mandate enforced and regulated by the Federal Communications Commission (FCC). The E911 requirement states that wireless carriers must provide E911 services to subscribers according to the following specifications. By 1 October 2001 each carrier had to be able to provide location accuracy via E911 of subscribers to within 50 to 300 meters using either self- or remote-position technologies. However, the cellular industry failed to meet this deadline. So, the FCC set a new deadline for this mandate to occur in late 2005 and the industry expects to meet this revised date. Additionally, the cellular industry has taken on its own standardization initiative for location based services with the creation of the Location Inter-operability Forum (LIF), a consortium of mobile phone manufacturers whose goal is standardization and system solutions among geolocation technologies (Evans 2003).

Geolocation by remote positioning through the cellular network is not a feasible method for many reasons. Aside from the cost of additional required infrastructure, the achievable accuracy is only 100 to 125 meters, which is easily achievable by global positioning systems. A radio tag developed for this type of geolocation would be relatively small and lightweight, usable for macro- and meso- mammals, and probably micro-mammals, but its limited accuracy negates its use. Animal inhabitants of urbanized landscapes tend to have smaller home ranges than inhabitants of more natural landscapes (Dykstra et al. 2001, Gehring and Swihart 2004, Mannan and Boal 2000, Kilpatrick and Spohr 2000). Thus, the system would have sufficient range but not sufficient accuracy.

Joshua Millspaugh (University of Missouri, person. commun.), believes use of the cellular network for telemetry purposes is a good idea and an avenue that should be pursued, given its great promise for the field and opportunity for innovation. Jean Bourassa (USDA-APHIS, person. commun.) suggests that with the development of a new technology, power management should be a focus. Currently, there are no known United States-based wildlife telemetry equipment suppliers that work with the cell phone system (Jennifer Bal, Telonics Inc. person. commun.). Geolocation by wireless communications systems is a relatively new market in the United States, and thus requirements and standards are still developing (Michael Buehrer, Dept. Electrical & Computer Engineering, Virginia Tech, person. commun.). A newly developed system would have to be integrated into the market structure of the highly competitive and regulated wireless communications arena.

The development of a cellular-based telemetry system will likely be a difficult undertaking. The difficulties involve the complexity of conducting interdisciplinary research and negotiating the telecommunications and wildlife telemetry industries. The three disciplines required for system development, wildlife biology and ecology, electrical engineering and wireless telecommunications, and sociology can be quite different with regards to their literature, vocabularies, concepts, and procedures.

Negotiating the existing industries and markets will more than likely prove to be difficult as was observed while conducting this research. The lack of commercial value to the wireless telecommunications industry creates little incentive for cooperation. However, it was suggested that there may be interest in cooperation within the industry for the purpose of public relations (Buehrer person. commun., Jeff Reed, Dept. Electrical & Computer Engineering, Virginia Tech, person. commun.). The wildlife telemetry industry may pose a difficulty from the perception of increased competition into a small-niche market, as would be expected with any market. It may be necessary to develop a technology transfer plan that involves the industry with the goal of increasing cooperation. The technology transfer plan may even be extended to include the wireless telecommunications industry thereby attempting to provide incentive for all stakeholders.

The target demographic for the development and use of a cellular based wildlife telemetry system encompasses those researchers and managers of urbanized landscapes. Urban ecologists and wildlife biologists, urban and non-game wildlife managers, human-wildlife conflict specialists, animal damage control specialists, and urban fringe (ex-urban and rural) researchers are expected to find the most use and value. Additionally, researchers whose focus is studying the fundamentals of the ecology and biology will find the instrument valuable and may provide new concepts through behavior, movement, or demographic data at a precision not yet attainable from the urban landscapes using existing systems.

Jeff Reed (person. commun.) noted that a technology developed for the wildlife sciences probably will not have an economically feasible commercial value, even though most cell phone service providers have found commercial value in offering E911 and targeted marketing services. Gene Coleman (Sprint Inc., person. commun.) stated that there is no commercialization opportunity for his company in wildlife technology. Using current cell phone costs to determine prices for other types of services is inaccurate because the cost of cell phones to the general public is less than the cost to make them; profits from cell phone services currently mitigate any incurred loss. Additionally, there is significantly more cell phone users than would be users of an urban wildlife telemetry technology, and thus distribution of costs would not be as great (Reed, person. commun.).

Buehrer (person. commun.) noted that, in the United States, if a geolocation mobile platform was developed using either angle of arrival or time of arrival techniques, it would need to have the functions of a transceiver to accommodate the either time division or code division multiple access networks. Additionally, geolocation calculations such as angle of arrival and time of arrival would have to be conducted by a service providing company because access to transmission information is considered a confidential information (Reed, person. commun.).

Furthermore, a simple system such as attaching an automated very high frequency system to cell towers is not a feasible solution as space on towers is very expensive and attaching/modifying existing towers requires an interruption in service (Reed, person. commun.).

Based upon all the preceding information, three feasible technological approaches for using cellular infrastructure for wildlife telemetry are provided below. First, the largest, but least feasible, at this time, is to develop wildlife telemetry as a location based service. This approach would entail working with telemetry equipment manufacturers or client hardware suppliers, mobile network providers, and either purchasing services from a location service provider and acting as the mobile portal service provider, or purchasing and co-locating a positioning server with an application server to act as a location service provider (see Figure 2). It may be less costly to purchase location services rather than establishing a location server as all federal regulations and coordination would have been conducted by the location services provider. Additionally, mobile network providers and location services could be purchased in bulk with an expected scaled decrease in cost and sold to researchers at cost much like local small cell-phone service providers currently do. An ideal location for this type of provider resides with a regional nation-wide monitoring infrastructure (e.g., National Ecological Observatory Network or U.S. Geological Survey, National Biological Information Infrastructure node). This structure already contains two of the three necessary components to complete the service: an application server and the geographic database. All that would be necessary to complete service is to add a positioning server or to purchase positioning services. However, a small business also could be established to provide these services. Stationing the wildlife telemetry location based service within a nation-wide monitoring infrastructure would allow it to compile and send the location data of the client's radio-tagged animals and provide all the additional available data already contained within its databases that the client may need (e.g., hydrology data, land cover data). More importantly, it could act as a repository of animal location data. Studies could be conducted at the individual, population, species, and community levels at large ecoregion scales, and allow assessments of climate, regional pollution, or other parameters in conjunction with animal location data. Finally, this approach requires the client hardware suppliers to develop and supply remote positioning radio tags/mobile platforms that comply with frequency, power supply, and infrastructure requirements of cellular networks. These

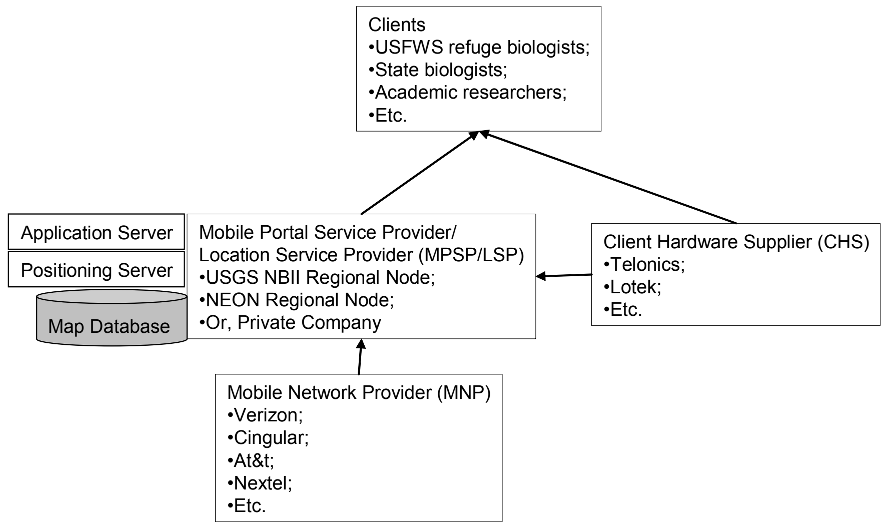

Figure 2. Proposed wildlife telemetry Location-based Service business model, an adapted from Jagoe (2003).

mobile platforms most likely would be feasible only for large or medium-sized animals.

The second and a more feasible approach is to develop mobile positioning platforms that determine geolocation by global positioning system, differential global positioning system, or wide-area augmentation system (WAAS). Bourassa (person. commun.) suggests working directly with telecommunications engineers to develop a GPS-based radio tag with a microprocessor that strictly manages power usage. With this approach, the cellular network would be used for its telematics capabilities to transmit calculated location data directly to a researcher's website or Internet server. However, due to the extensive amount of electronics required for the mobile platform, this approach most likely would be feasible only for large mammals. International companies already offer wildlife telemetry equipment that works over the GSM network, but here in the United States, no companies presently offer a type of system compatible with code division or time difference multiple access systems. This approach would still be constrained by the limitations of GPS in urbanized landscapes.

The third and most feasible approach for studying urban wildlife and urban ecology involves ultra wide band (UWB) for geolocation of animals (Buehrer, person. commun.). Ultra wide band transmits extremely short pulses of extremely low power across a range of frequencies at once. Thus, it is not affected by multipath or interference-caused error, it consumes very little power to conduct its functions, transmitters can be made small in size and weight, is 3-D positioning capable with precision to within twelve inches, and has a functional range of up to two kilometers. The small size of transmitters with this system makes it feasible for small and medium animals, and large animals with limited ranges. Additionally, ultra-wide band can be used indoors, but with range reduced to about 300 meters. Buehrer (person. commun.) believes a ultra wide band geolocation system could be developed for about $10 per transmitter and $200-$300 per receiver, with a minimum requirement of three receivers. Receivers could be attached to light poles instead of cell towers and signals could be received by the ultra-wide band geolocation system and transmitted to the researcher or third party via a wireless local area network or other telecommunications network. He believes such a system could be fundable through the National Science Foundation. Reed (person. commun.) suggests using a wireless local area network system referred to as WI-

MAX as a telematics platform for transferring global positioning system geolocated data. The WI-MAX system, which is a wide area extension of the WI-FI system, would provide a range up to 30 miles with relatively low power demand.

The likelihood of developing a cellular network based wildlife telemetry system is good. As interest in studying urbanized ecosystems and finding resolution to human-wildlife conflicts increases, so does value of such a system. Funding to develop a system could be acquired from sources not normally considered for traditional wildlife telemetry. The possibility of acquiring sponsorship through cellular telecommunications is fair. The research into telemetry system development, being interdisciplinary, is very attractive to grant and funding programs. Upon casual observation, there appears to be interest from wildlife research grant programs in innovative technologies for wildlife biology and ecology. Thus, the acquisition of development and research funding and creation of a cellular based telemetry system for urbanized landscapes is likely if all stakeholders and constraints are addressed in the planning and development of the system.

Conclusions

Telemetry-derived location information tools have become a mainstay in wildlife biology and have become more precise and efficient as the technology advances. Urbanized landscapes present very different restrictions and requirements for ecological study that constrain the effective use of existing telemetry technologies. If we are to successfully expand research and understanding into this new urbanized landscape, new tools will be necessary to mitigate restrictions and requirements.

The extant literature provides information on current use and limitations of existing telemetry technologies used by researchers and offers guidance on the feasibility of using cellular telecommunications networks in the future. The cellular infrastructure could be used to lower costs of telemetry data and improve information gleaned from urban studies. My research into the possible geolocation methods, hardware requirements, issues, and existing and future directions of telecommunications technologies and markets revealed three feasible systems for using the existing network: location-based service systems, mobile positioning mobile platforms (GPS), and UWB geolocation subsystem. Although each of these three systems possess some degree of feasibility, the most feasible approach combines an ad hoc/telematics system for data transferal and ultra-wide band technology for geolocation determination, an approach some experts believe is fundable.

The cellular network and the research from this study should be used for the purpose of advancing urban ecology and wildlife biology. Due to the constraints of animals residing in smaller geographic areas, limited access for researchers to those areas, and limited supply of research money for the study of the urban life sciences, instruments and tools must be designed for maximum precision, automation, and be available at minimum economic cost. The research and conclusions in this paper should be used to design and develop a cellular-based wildlife telemetry system.

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Appendix I

An Ultra-Wide Band Telemetry System
For
Animal Radio Tracking in Urbanized Landscapes

Insert Submission Date

A Proposal Submitted To:

Insert Grant Program Title
And Contact Information

Submitted By:

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Abstract

Human populations inhabiting urban landscapes have increased from 224 million in 1900 to 2.9 billion in 1999. The wildlife biology profession utilizes telemetry derived location information for ecological and management studies that involve movement, behavior, habitat use, survival, productivity, and others. World-wide there were more than 1.2 billion cellular telephone users in 2003. A cellular phone based telemetry system is a feasible technology to assist wildlife biologists and researchers overcome the obstacles and requirements for conducting research in urbanized landscapes. A study will be conducted to develop a wildlife telemetry system for urban landscapes that combines ultra-wide band technology and an ad hoc telematics cellular network system. The results of this project will provide a newly developed automated telemetry system for urbanized landscapes that is more economical and precise than currently available telemetry systems.

An Ultra-Wide Band Telemetry System
For
Animal Radio Tracking in Urbanized Landscapes

Problem Statement

Human populations inhabiting urban landscapes have increased from 224 million in 1900 to 2.9 billion in 1999. Over the next 30 years that population is expected to increase by another 2 billion and encompass more than 60% of the world's total human population according to the United Nations (Alberti 2003, Traut et al. 2003). Biological and physical properties of urban landscapes are redistributed by their human inhabitants. Mechanisms such as traffic congestion, sprawl, and air pollution are some means by which this is achieved. These mechanisms interact with other properties of the urban landscape such as topography, social preferences, and urban infrastructure to provide a significantly different ecosystem than those non-urban landscapes (Alberti et al. 2003). Anthropogenic activity has significantly altered the North American non-urban landscapes by fragmentation, loss, and introductions of ill-adapted ecosystem disturbance regimes. The transformation of non-urban to urban landscapes tends to follow the pattern of agriculture to urban use (Salsbury et al. 2004). Turner et al. (2004) submits that urban human populations live in a state of biological poverty. Urban landscapes do hold specific features such as mosaic patterns, rigid disturbance regimes, exotic species introduction and extinction, and reorganization of communities within the ecosystem. Due partly to these specific urban features, ecologists should be drawn to urban landscapes to test fundamentals of their discipline and solve problems (Rebele 1994).

Urban ecology is the nexus of social, biological, and economic sciences. Its understanding should be used to integrate social and biological information (Alberti et al. 2003). Due to the alteration of natural habitats to agriculture and urban landscapes, the examination of urban areas as habitat is necessary for effective species management (Salsbury et al. 2004, Traut et al. 2003). Alberti et al. (2003) presents fundamental considerations to determine resilience of urbanized landscapes for the study of urban ecology such as how does human activity and populations interact with individual, population, and community processes in an ecosystem?

Turner et al. (2004) concluded that it is possible to sustain a certain level of biodiversity in urban landscapes. Both inner urban and fringe ex-urban landscapes hold promise for biodiversity and biological interactions. However, the study of these features must be increased significantly to provide information for more compatible urban development. Although, generally disinterested in ecology of the landscape, urbanites may observe and understand that ecological features are necessary to the urban environment. They may appeal to the aesthetic values of those features most of all (Manuel 2003). The study of wildlife in urban landscapes calls for re-evaluation of traditional techniques employed by the biologist (Hegglin et al. 2004). Persistence of wildlife in urban landscapes is highly correlated to available resources. The study of wildlife in urban landscapes promises not only to add to the sub-discipline but to the field of ecology on a whole (Geggie and Fenton 1985).

The wildlife biology profession utilizes telemetry derived location information for ecological and management studies that involve movement, behavior, habitat use, survival, productivity, and others. Two telemetry techniques used by biologists for geolocation determination are homing and trilateration. Ever since the first functional telemetry system created by Cochran and Lord (1963) technologies for wildlife telemetry have improved. These improved technologies include refinements to the standard very high frequency (VHF) systems, the development of geographic positioning systems (GPS) for telemetry uses, a satellite-based telemetry system, and combinations of current systems.

New technologies and techniques that could be used by wildlife biologists for urban wildlife research and management are necessary for research in this landscape type. Currently, there are no known technologies for wildlife telemetry designed for the specific limitations presented by the urbanized landscape. Techniques and technologies that are better suited for urban settings but provide the same types of data are ideal. They ensure statistically compatible data for comparison with other landscape types and the use of historical data collected by traditional techniques and technologies does not become obsolete. New technologies, such as ultra-wide band (UWB) and cellular telecommunications, are ideal for designing new telemetry systems that comply with the limitations of urbanized landscapes. A new technology for wildlife telemetry designed for use in urbanized landscapes is necessary to promote increased and further research in urban ecology and its super-discipline.

The cellular telecommunications network combined with the new technology of ultra-wide band will provide a data transfer network and geolocation method designed specifically for the urbanized landscape.

It is logical to conclude that the cellular telecommunication network is most suitable for use in developing a wildlife telemetry system for urbanized landscapes. It provides a pre-established and expanding array of receivers, optimized for use in the landscape. In the United States use of the network for geolocation has primarily taken on the form of a telematics network by the addition of global positioning system to commercially available cell phones. Since geolocation in the cellular network is usually accomplished by means of a subsystem, in the case of a cell phone – GPS, the development of an urban wildlife telemetry system should correspond accordingly. The subsystem most suitable for geolocation in the settings of an urbanized landscape is ultra-wide band.

Ultra-wide band, developed in the 1960's by the United States Department of Defense for security and defense purposes, is a fairly new technology to industry and the general public. It is lauded by industry as having the ability for high data transfer rates, at low power, over short geographic ranges. Why would a technology developed for short range and high data transfer be useful for a purpose with seemingly opposing performance requirements? Ultra-wide band also has properties that are advantageous in urbanized landscapes. The technology is less affected by multipath error than existing approaches to geolocation of wildlife. It has the ability to accommodate seemingly limitless mobile units, is low power and thus allows for the use of small transmitters, and is comparable in hardware and operational expense to traditional very high frequency telemetry methods. These properties make ultra-wide band advantageous for both automated and manually operated telemetry systems.

The single disadvantage to using ultra-wide band for geolocation is the technologies' limited range. A transmitter's signal is detectable, in favorable conditions, at a maximum of approximately two kilometers and one kilometer in typical conditions. Favorable conditions for telemetry include line-of-sight in flat terrain and temperate weather conditions. Individuals from target species likely to be subject of research are generally found to have decreased home ranges in urbanized landscapes as compared to those in un-urbanized landscapes (Dykstra et al. 2001, Gehring and Swihart 2004, Mannan and Boal 2000, Kilpatrick and Spohr 2000). The likely decrease in home range does favor the use of ultra-wide band for this case but may not completely compensate the technologies limitation for some wide-ranging species. For extreme cases, such as wide-ranging species, ultra-wide band's advantage of being low cost will mitigate the limitation. Ultra-wide band hardware and operational costs are low compared to existing wildlife telemetry systems. So, to establish an automated system, saturating a study site with receivers will mitigate the technologies range disadvantage.

As the United States and the world human population continues to migrate towards urbanized landscapes and as the expansion of those landscapes continues to increase to accommodate this growing population, increased study of urban ecology and wildlife is necessary to better support compatible urban development. It also provides great opportunity to test accepted ecological principles. However, study in urbanized landscape types present the researcher with different restrictions and opportunities. The development of research tools designed to take advantage of both the opportunities and restrictions while providing compatible data with studies from other landscape types is necessary to take full advantage of this human migration phenomenon. As technology progresses and robust technological infrastructure is established, the potential for new research tools increases. The combination of the cellular telecommunications network as a telematics platform partnered with an ultra-wide band geolocation subsystem will provide a solution to the need for research tools suited to study in urbanized landscapes.

Objectives

This study will develop a new telemetry system for the study of wildlife in urbanized landscapes. It will test the new system in controlled and field settings to determine operational capabilities across different urbanized landscape types and fulfill the following four objectives.

1. Develop a telemetry system that accomplishes geolocation by both homing and trilateration means using ultra-wide band.

2. Assess the system's suitability for homing to transmitters, to include homing through solid barriers (e.g., brick walls) to assess ability to locate den sites in both controlled and field settings.
3. In a controlled manner, assess the system's suitability for trilateration in four urbanized landscapes to include: inner urban, suburban, exurban, and rural; and establish an automated system in one of the four urbanized landscape types.
4. In field settings, assess the system's suitability for trilateration in the same four landscapes tested for objective three on micro-, meso-, and macro-mammals.

Materials and Methods

A project will be performed to achieve the above outlined objectives. A telemetry system will be developed that achieves precise geolocation measurements and enhanced homing capabilities using ultra-wide band technology and the cellular telecommunications network.

Utilizing the vast experience and research on wireless telecommunications and ultra-wide band technology from Virginia Tech's Department of Electrical and Computer Engineering and the wildlife biologist experience of Virginia Tech's College of Natural Resources, the researchers will design a system or set of two systems that will be able to accommodate the two methods of geolocation most employed by wildlife ecologists: homing, and trilateration. The project focus will be on development of an automated telemetry system but may include the development of a manual version to accommodate the homing geolocation method.

To assess the system for its homing and trilateration capabilities, researchers will test the system in each of four urbanized landscape types: inner urban, suburban, exurban, and rural. All these landscape types will be selected from the greater metropolitan Washington area, further information on the study sites can be seen in the Study Area section of this proposal.

Upon completion of prototype development, it will be tested in controlled settings. Controlled settings for the purpose of this project entail recreated conditions in which the system will likely be employed. For example, to test the capabilities of the prototype, transmitters will be placed in buildings, tree cavities, open space, and densely covered forested areas to determine precision, range, and other performance characteristics for both homing and trilateration techniques. Following controlled testing of the prototype, an assessment of the capability testing will be conducted and modifications will be made, if deemed necessary. The controlled testing process may be repeated once or twice more, if necessary, to improve prototype performance.

Once an acceptable prototype is achieved, field testing will commence. Field testing of the system will entail attaching prototype system transmitters to three small, medium, and large mammals trapped in each of the four landscape types. Some animal types may not be found in a specific landscape type and thus will be excluded from that specific testing scenario; for example, large mammals may not reside in inner urban landscapes. Testing will commence for twelve months or until transmitter battery power is depleted. Towards the completion of the tenth month, researchers will retrieve all transmitters to assess condition to individual animals and equipment. All trapping and handling of animals will follow strict protocol conducted and/or overseen by experienced wildlife biologists. The Institutional Animal Care and Use Committee will review this proposal. More information on animal trapping and handling of wildlife can be found in the Special Provisions section of this document.

Results of all control and field testing will be documented for publication.

Special Provisions

During field testing of the project animals will be trapped and handled. Specific actions will be taken to minimize stress resulting from trapping and handling procedures. Only live and clover traps will be used to capture animals. All animals will be blind-folded and restrained with the utmost care. Physiological stress indicators will be monitored during periods of animal restraint and will be used to determine if field procedures should be aborted. Finally, all transmitter attachments will be non-intrusive and follow design specifications per species for collar or harness size found in current literature.

All necessary permits will be acquired for scientific collecting in the states of Maryland and Virginia from their respective natural resources departments. Additionally, if any field work is conducted on federal properties then the appropriate scientific collection permit(s) will be obtained from the required management agencies.

Additionally, all testing and the resultant system will comply with all FCC mandates, restrictions, and requirements.

Study Area

The project fieldwork will be conducted on both public and private land in the greater metropolitan Washington area. The specific study areas for the field testing will include: Loudon County, VA; Fairfax County, VA; Prince William County, VA; Arlington County, VA; and the City of Alexandria, VA. The controlled testing of the system will be conducted on both public and private properties. All work conducted will be preceded by the acquisition of all appropriate permissions and restrictions established by the property owner and/or manager. All lab and development work will be conducted at Virginia Tech.

Project Deliverables

The project will result in the development of a new telemetry system or set of two systems for geolocation of wildlife specifically tailored for study in urbanized landscapes. The new technology will be publicized through both scientific publications and conference proceedings, and will be transferred to private industry for development and distribution via Virginia Tech Intellectual Properties, Inc.

An overview of the system, the results from tests determining its operational capabilities, and any marked innovations will be published in two different scientific journals. One journal will be chosen to address biologists and ecologists and the other will be chosen to address electrical engineers. Also, the technology will be presented at four different conferences or symposiums with two conferences being of ecological or biological focus and two of electrical engineering.

Project Schedule

The prototype receiver and transmitter system development will start in September 2005 and continue for twelve months. Following completion of the prototype development controlled testing will commence for one month. Field testing will be conducted for nine months following all controlled testing. All data analysis and manuscript preparation will be completed by September 2007.

Budget Requirements (2005-2007)

A. Personnel	
Faculty Member (5% time)	$12,000.00
Faculty Member (25% time)	$60,000.00
Graduate Research Assistant	$50,000.00
Graduate Research Assistant	$40,000.00
B. Contract Services	
Electrical Engineering Lab Rental (includes computer and analysis equipment)	$10,000.00
C. Other Direct Costs	
One prototype, or set of two, receiving system(s) hardware	$25,000.00
50 prototype transmitter tags	$10,000.00
12 months of wireless and/or cellular service	$1,000.00
Traps, bait, and associated equipment	$500.00
Sedatives and associated equipment	$300.00
Ear tags	$30.00
Permit fees	$300.00
Conference travel	$2,500.00
Journal page charges	$2,500.00
D. Indirect costs – VPI&SU indirect rate is 27.6% for off-site locations (such as the National Capital Region)	$59,100.00
E. Fringe Benefits	
Faculty Members	$22,500.00
Graduate Research Assistants	$2,500.00
Total	**$273,230.00**

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Glossary

Angle of Arrival (AOA) A remote-based method of determining position where multiple base stations having additional equipment that determines compass direction from which the user's signal is arriving by triangulation.

Cell The radio coverage area of a single base station in a cellular network.

Code Division Multiple Access (CDMA) A means of splitting radio channels depending on codes rather than splitting into time slots and frequencies.

Cell of Origin (COO) A remote-based positioning solution where the latitude and longitude coordinates of the base station serving the mobile device is used as the location of the user. A cell, and thus, the accuracy can vary from 100 to 1,000 meters.

Differential Global Positioning System (DGPS) A method to increase GPS accuracy during selective availability by using a reference signal from a known position.

Enhanced-Observed Time Difference (E-OTD) A mobile terminal-based positioning solution where the difference in the time it takes to receive data from surrounding base stations is used in trilateration to determine position.

Frequency Division Multiple Access (FDMA) A radio transmitting system where one carrier frequency is allocated to each mobile station.

General Packet Radio Service (GPRS) A wireless communications standard that is faster than GSM which supports a wide range of bandwidths by sending and receiving bursts of data.

Global System for Mobile Communications (GSM) Developed in Europe as Groupe Speciale Mobile, it was intended as a common standard for the digital mobile telephone network.

Industrial, Scientific, and Medical band (ISM) A band of radio frequencies that is unregulated in the United States for use with industrial, scientific, and medical purposes.

Space Division Multiple Access (SDMA) Digital mobile telephony system where the same frequency is used in sending and receiving data but is allocated by different points in space to accommodate many users.

Transmission Control Protocol/Internet Protocol (TCP/IP) A system devised for coordinating the transfer of data over networks. It has grown to become the foundation for the Internet.

Time Division Multiple Access (TDMA) Digital mobile telephony system deployed in the United States based on the same principles as GSM.

Time Difference of Arrival (TDOA) Similar to TOA, time difference of arrival measures the time difference between two signals.

Time of Arrival (TOA) A way of measuring the distance from the mobile station to the base station via trilateration.

Uplink-Time of Arrival (UL-TOA) A way of measuring the distance from a mobile to a minimum of four base stations by measuring the signal runtimes between the two terminals. It can produce a precision of 50-150 meters.

Universal Mobile Telecommunications System (UMTS) The standard for third generation cellular networks for use throughout Europe and Japan.

Wireless Fidelity (WI-FI) A term used when referring to any type of IEEE 802.11 network. The radio technologies most often used in wireless local area networks (WLAN).

WI-MAX A term used when referring to a IEEE 802.16 network. The radio technology used for fixed broadband wireless metropolitan access networks, an extended range version, typically 30 miles, of a WLAN.

Vitae

John Matthews Stokely

John M. Stokely has worked with and studied multiple different species, populations, communities, and ecosystems. He obtained his undergraduate education in Wildlife Management from Unity College in Maine. There he was able to study the northern hardwood and conifer ecosystems. Following his undergraduate studies, John, worked in Virginia for the National Park Service studying warm-water fishery communities, urban deer populations, non-native vegetative populations, and wetland communities. Following work in Virginia, John, pursued work in the semi-arid and arid environments of the North American southwest. While working in California, he assisted with feral animal removal and studied animal movement for a large-scale ecosystem restoration project on Santa Catalina Island. John also studied and investigated the decline of a federally categorized threatened species, the Catalina Island fox (*Urocyon littoralis catalinea*). John left Catalina to work on mule deer (*Odocoileus hemionus*) for the California Department of Fish and Game where he developed methodology for tracking previously unmapped migration patterns of remotely located herds in the Sierra Nevada. Currently, John is working for a private environmental consulting firm conducting conservation work in conjunction with the Army Environmental Center. Some projects he is currently working on are a spatial decision support tool for conservation reserve design and consultation regarding endangered species. When not working, John tries to promote the ecosystems he studies by teaching stream conservation classes at summer camps and volunteering his services as an ecologist and biologist at local parks and conservation organizations.