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Re:	Supporting Comment to the SRD
Abstract	This contribution provides background and motivation for machine-to-machine (M2M) communications in 802.16 cellular networks.
Purpose	For IEEE 802.16m discussion and eventual adoption
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M2M mode in 802.16m

1. Introduction

Machine-to-machine (M2M) communications could be defined as communications from or to a device that is not directly employed by humans. A variety of devices such as sensors, location tags, machines and meters can be said to originate or terminate M2M communication. M2M communications has been deployed for several decades in many different scenarios. In particular, cellular networks are already being used for M2M communications.

While there has been a strong push for enhancing cellular communications for voice and high speed data applications through multiple generations of evolution, optimizing the network for M2M communications has received little attention. This is justifiable considering that majority of the revenues have originated from voice communication, and more recently, increasingly from bandwidth hungry data applications. With voice penetration reaching maximum possible levels in most developed countries, there is evidence that operators are beginning to focus their attention on other applications and services, M2M communications being among them. The number of machines is at least an order of magnitude larger than the number of people in the world offering a huge potential market for cellular communications that cannot be ignored.

It is fair to say that M2M communications have not taken off as one would have expected. Market analysts have revised their estimates for the number of M2M devices downwards multiple times over the past few years. Current projections for the number of cellular M2M modules world-wide in five years, around 2012-2013, by several market research firms revolve around the 200 Million mark, a number that is much smaller than what one would expect given the very large number of devices that could potentially be connected probably because of the high cost of devices. With lower cost modules, it is highly likely that a significantly larger number of applications will employ cellular communications.

Standardization activities that are currently on-going provide an opportunity for incorporating several features that can enhance M2M adoption. In particular, one can consider introducing an “M2M mode” of communication within the air-interface that facilitates low power, low complexity communication resulting in more efficient lower cost M2M communication. This should drive a faster rate of adoption for M2M communications.

802.16m is one of the most spectrally efficient cellular systems that are capable of carrying Internet data traffic are well suited for introducing some enhancements to carry M2M traffic. Incorporating M2M specific features now will prove to be quite beneficial in the future.

2. Targeted Applications and their characteristics

M2M applications are very diverse and can vary significantly in their communication requirements. The applications of interest to cellular M2M communications are the ones where a wide area wireless network is required for communication. For such applications existing low power networking technologies such as IEEE 802.15.4, or local area networking solutions such as WiFi, do not meet the range requirements or mobility requirements. Thus a wide area network such as the cellular network is required.

Table 1 below shows a number of M2M applications that require wide area communication. One might think that applications such as vending or meter reading could be performed using a local area network. However, in many cases direct cellular connection is preferred. For example, in the case of vending or machine monitoring, for security reasons the vending or machine (e.g. photocopy machine inside a building) operator will not be allowed access to the corporate LAN network and thus will prefer vending machines with direct Internet access.

For several of the applications in the table, low communication rate will be satisfactory. However, extended coverage will be quite beneficial. In particular, being able to close the reverse link with low transmission power will be preferred to reduce cost of the M2M modules. Another characteristic of several applications is that there is no need for supporting mobility. Eliminating a large of number of features related to seamless handoffs for the M2M modules can significantly reduce complexity.

Of course some of the M2M applications such as video sensing do require high data rate communication. Such applications will likely be supported most effectively on next generation broadband air-interfaces. But there are a significant number of applications that fall into the category of requiring occasional, small payload, low rate communication that some air-interface modifications to existing air-interfaces can be beneficial.

Application	Examples	Access Frequency (sessions/ unit time)	Number of Payload bytes/ session
Vending	Initially for high value items such as phone cards, cigarettes for inventory management	<5 times/day	small (10s of bytes)
Machine monitoring/SCADA	Photocopiers, elevators, industrial machines, game machines where no access to local LAN for security reasons	<5 times/day	small
Automated meter reading	Electricity, gas meter reading	<5 times/day	small
Smart metering	Providing prices to end users for demand response, per appliance metering, parking meters	~50 times/day	small
Home security	As a backup to phone line or broadband	Rarely	small
Environmental Sensing	temperature, humidity, strain, road etc	Varied	small (if not
Vehicle Tracking	Occassional need to locate vehicle (theft, lost in parking lot etc.)	Rarely	small
Point of Sale	gas stations, rental returns	~1000 times/day	medium (10
Displays and Billboards	Traffic information on roads, dynamically changing advertisements, bus arrival times	1~100 times/day ~1000 times/day	small to several Megabytes
Remote Video Surveillance	Toll/speed cameras(?), remote entrances to buildings, oil pipe lines etc.	continuous; rare if event triggered	MBytes/s
Fleet Management	car rental, taxis, trucks, staff scheduling	~10-100 times/day	small to Mbytes
Driver/Vehicle Performance Monitoring	Vehicle diagnostics(send back information on condition of car), travel speed, etc.	~10-100 times/day	~1000
VehicleTraffic Information/Routing/Navigation	Provide real-time traffic and rerouting	continuous	Kbytes/s
Telemedicine	Heart rate/ausculation rate	continuous when triggered	Kbytes/s to Mbytes/s

Table 1 Some M2M applications and their requirements

3. Limitations of short range, unlicensed band communications technologies

Several communication technologies have been designed specifically for sensor communication. For example, IEEE 802.15.4 is PHY/MAC standard for low power personal area networks which has been employed by Zigbee forum for sensor networks, in particular, for home automation, energy management and industrial automation. Z-Wave is an alternative proprietary technology for similar applications. Bluetooth is also a low power personal area network mostly targeting a different set of applications such as wireless headsets.

The primary issues with these solutions are the fact that they are designed for unlicensed bands and are typically short range. It is of course possible that the range, say for 802.15.4 system, can potentially be extended through more sophisticated receivers and higher transmit powers. However, the fact that it uses unlicensed spectrum implies that in a wide area setting interference cannot be controlled and performance guarantees are not possible. There are no wide area networks in the unlicensed bands deployed to date. Municipal WiFi was an attempt at building a wide area network using unlicensed spectrum, but appears to be failing in the market.

Finally, none of these standards support mobility, which is essential for some of the M2M applications. Similarly, some of the M2M applications require high data rates in a wide area setting that are currently only feasible using cellular networks. Thus cellular networks have the potential to provide a unified, efficient solution for a wide variety of M2M applications that require long range wireless communication.

4. What are some desirable features?

a. Introduction of new terminal class targeting M2M modules

M2M terminals need not have all of the functionalities of a full-fledged voice terminal. They can support fewer features such as reduced set of coding and modulation rates, hybrid ARQ modes. Thus it is beneficial to have a separate class for such terminals with their own set of minimum requirements for testing.

b. Low power operation

A class of M2M applications, for example environmental sensing, is likely to be battery operated. Battery life for such sensors is critical to the success of the application. Being able to close the link with lower transmission powers will thus open up the cellular interface for a number of new applications thereby increasing the number of devices using cellular networks. Closing the link at low powers is feasible because low data rate transmission is sufficient for many such applications.

Even when devices are not battery operated, limiting the transmit power can result in lower terminal costs. Low power operation could reduce the filtering requirements since adjacent carrier interference will be reduced. Thus it is beneficial to have a requirement such as “provide 95% coverage (existing coverage area criterion) with transmit powers 15 to 20 dB less transmit power" at a suitable transmission rate which could be as low as 1 Kbps. It should be noted that it not expected that range will be extended and transmitted power lowered concurrently.

c. Extended Range

Complementary to the low power requirement, we could take advantage of the low data rate requirements to extend the range instead. Since some of the M2M devices could be inside buildings it would be beneficial to extend the coverage for low data rates specifically meant for M2M communication.

d. Reduced base band complexity

Baseband complexity of next generation cellular networks is significant. We advocate simplifications to lower complexity for a class of terminals in order to reduce module costs. Several simplifications are possible. For example, make before break handoff is not required for M2M communication. This can eliminate the need for multiple simultaneous pilot searchers.

e. Scalability

Because of the low duty cycle, low throughput, and data transfer requirements of some of the applications, from an air-interface capacity point of view it would be possible to support a very large number of devices. However, it is necessary to ensure that other system aspects can handle a large number of devices, most of them in the dormant state.

5. Feasibility for extending link budget

A sample link budget for 802.16m on the reverse link for 1.2 Kbps data rate shows that with 10 dBm it is possible to achieve the same maximum path loss as the current lowest rate of 4.8 Kbps. Extended range (captured through additional 15 dB of penetration loss) comes to within 5 dB of the current lowest rate. We have assumed some special interference management strategy (for example. transmitting during dead hour) so that the interference margin can be reduced.

	Downlink				
	Transmitter	**802.16e**	**Units**	**Symbols / Comments**	**Additional Comments**
1	Transmit Power	43	dBm	a / TPO	Per antenna Tx Power
2	Antenna Gain	17.5	dBi	b	65 degree antenna?
3	Cable Loss	0	dB	c / Specify cable type	Tower Mounted Amplifier Assumed
4	Tx Ant. Div. Gain (non-coherent)	0	dB	c1 / Specify # of antennas	Antennas used for beamforming
5	Tx Smart Ant. Gain	10	dB	c2 / Specify # of	4 Tx Antennas

	(coherent)			antennas	
6	Backoff	8	dB	d / reduction for PAPR	
7	**EIRP**	**62.5**	dBm	e=a+b-c+d+c1+c2	
	Receiver				
8	Thermal Noise (KT)	-174.0	dBm/Hz	f	
9	Noise Figure (SS)	8.0	dB	g	
10	Channel Bandwidth	5.0	MHz	NA / Specify expectation	See Notes Page
11	Effective Noise Bandwidth	4.8	MHz	h	Accounting for guard tones
12	Receiver Noise Floor	-99.2	dBm	j=f+g+10*log(h*10^6)	
13	Information Bit Rate	512.0	Kbps	NA / Provide kbps/SNR table	See"PHY Specifics" Attachement
14	Required SNR	5.5	dB	k / for specified bit rate	
15	**Receiver Sensitivity**	**-93.7**	dBm	l=j+k	
16	Receiver Antenna Gain	2.0	dBi	m	
17	Rx Ant Diversity Gain	0.0	dB	m1	1 Rx antennas at CPE
18	**Max Path Loss w/o Margins**	**158.2**	dB	n=e-l+m+m1	
	Margins/Gains				
19	Interference Margin	6.0	dB	o	
20	Log Normal Fading Margin	13.0	dB	p	90% cell edge coverage
21	In-building Penetration Loss	15.0	dB	q	Suburban
22	Body Loss	0.0	dB	r / if applicable	
23	Transmit Antenna Diversity Gain	0.0	dB	s	
24	Transmit Smart Antenna Gain	0.0	dB	t	
25	Receiver Antenna Diversity Gain	0.0	dB	u	1 Rx antenna at CPE
26	Receiver Smart Antenna Gain	0.0	dB	v	
27	Other Gains (must be specified)	4.5	dB	w	Best Sector Selection
28	Other Margins (must be specified)	4.5	dB	x	Margin relative to UL
29	**Total Margins**	**34.0**	dB	y=o+p+q+r-s-t-u-v-w+x	
30	**Maximum Allowable Path Loss**	**124.2**	dB	z=n-y	
	Uplink				
	Transmitter	**802.16e**	**Units**	**Symbols**	
1	Transmit Power	27.0	dBm	a	PCMCIA device
2	Antenna Gain	2.0	dBi	b / reduce by cable loss as required	
3	Backoff	9.0	dB	c1 / reduction for	

				PAPR	
4	**EIRP**	**20.0**	dBm	c=a+b-c1	
	Receiver				
5	Thermal Noise (KT)	-174.0	dBm/Hz	d	
6	Noise Figure (BS)	4.00	dB	e	
7	Channel Bandwidth	5.00	MHz	NA / Specify expectation	See Notes Page
8	Effective Noise Bandwidth	0.54	MHz	f	535.7 kHz for 2 subchannels for 416 kbps
9	Receiver Noise Floor	-112.7	dBm	g=d+e+10*log(f*10^6)	
10	Information Bit Rate	256.0	Kbps	NA / Provide kbps/SNR table	See"PHY Specifics" Attachement
11	Required SNR	5.5	dB	h / for specified bit rate	
12	**Receiver Sensitivity**	**-107.2**	dBm	j=g+h	
13	Receiver Antenna Gain	18.0	dBi	k	
14	Rx Ant non-Coherent MRC Gain	0.00	dB	k1 / Specify # of antennas	1
15	Receiver Antenna Cable Loss	0.5	dB	l / Specify cable type	Connector loss
16	**Max Path Loss w/o Margins**	**144.7**	dB	m=c-j+k+k1-l	
	Margins/Gains				
17	Interference Margin	3.0	dB	n	
18	Log Normal Fading Margin	13.0	dB	o	90% cell edge coverage
19	In-building Penetration Loss	15.0	dB	p	Suburban
20	Body Loss	0.0	dB	p1 / if applicable	
21	Transmit Antenna Diversity Gain	0.0	dB	q	
22	Transmit Smart Antenna Gain	0.0	dB	r	
23	Receiver Antenna Diversity Gain	6.0	dB	s	4 BTS Rx Antennas
24	Receiver Smart Antenna Gain	0.0	dB	t	
25	Other Gains (must be specified)	4.5	dB	u	Best Sector Selection
26	Other Margins (must be specified)	0.0	dB	v	
27	**Total Margins**	**20.5**	dB	w=n+o+p+p1-q-r-s-t-u+v	
28	**Maximum Allowable Path Loss**	**124.2**	dB	x=m-w	

Table 2 Sample reverse link budget for low power transmission and extended range options

6. Some proposed Modifications

a. Low data rate option

Introduce a new lower rate option in the reverse link to support low power or extended range operation. Lower rate can be around 1 Kbps. Alternate coding techniques could potentially be considered for this rate option. Lower rate option should be for both traffic and access channel since access channel should not become the limitation.

b. Relaxed filtering requirements

For low transmit power terminals, the possibility of relaxing the filtering requirements and still meeting the spectral mask/adjacent channel transmission power leakage limits should be investigated. Relaxed filtering requirements can potentially reduce the cost of the terminals.

c. Elimination of multi-code requirement

Multi-code transmission increases the peak-to-average power ratio thus requiring a higher backoff and thereby limiting the range. Techniques to work around the need for multi-code transmissions should be investigated.

d. Elimination of seamless handoff

M2M applications generally do not require make before break seamless handoffs. This offers an opportunity to simply the base band significantly by tracking only a single sector pilot at a given time. There is no need for multiple searchers.

e. Reservation mechanisms

Investigate methods to reserve certain times exclusively for M2M communications on the reverse link to minimize interference. Furthermore, adjacent sector interference could also be potentially reduced through proper reservation mechanisms spanning multiple cells.

f. Preamble/Broadcast repetition for increased downlink range

Broadcast and synchronization (such as preamble) can be repeated more often at particular times so that the downlink range can be extended.