Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Amendment of the Commission's Rules	)	ET Docket No. 08-59
To Provide Spectrum for the Operation of	)	
Medical Body Area Networks	)	

To: The Commission

COMMENTS OF PHILIPS HEALTHCARE SYSTEMS

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SUMMARY

Philips strongly supports the proposed allocation of 40 MHz at 2360-2400 MHz for Medical Body Area Network ("MBAN") systems. Employing wireless devices to monitor patients in this underused spectrum is critical to achieving the national goals set out by Congress earlier this year in the HITECH Act of improving patient care, creating electronic health records, and reducing healthcare costs. The requested spectrum is uniquely suitable to meet the need for MBAN devices and can be used for this purpose without creating interference to the existing users.

The 2360-2400 MHz spectrum will allow exceedingly low power sensors to be manufactured inexpensively by leveraging existing technologies already developed for the neighboring Part 15 unlicensed and Part 18 ISM band at 2400-2483.5 MHz. The propagation characteristics of this band are particularly favorable for using just 1 milliWatt for in-hospital sensors – enough to travel the short distance needed to be received by an in-room receiver for relay to the monitoring network.

Use of higher bands, such as the 5150-5250 MHz UNII band, would require substantially more power that would work against development of disposable sensors and batteries because of the higher power consumption required. Using small disjointed blocks of spectrum, such as 2300-2305 and 2395-2400 MHz or the WMTS allocation, would not provide the capacity necessary to serve the need for these devices at hospitals.

Coexistence with primary users of the 2360-2400 MHz band is feasible, as demonstrated by Philips in Appendix E. Philips supports using exclusion zones and coordination to protect AMT receivers, coupled with contention-based technologies to monitor and change frequencies as needed to avoid interference outside of the exclusion zones. Applying traditional analysis indicates that an exclusion zone of 11.5 km maximum would protect the AMT receivers. Cognitive and adaptive technologies can be used to provide additional protection to AMT and amateur radio users. Since many of the AMT receive sites are in less populated areas, many large hospitals will be well separated geographically from the protected sites.

Philips also supports use of technology requiring an authentication key to enable transmissions in the 2360-2390 MHz band as an additional safety measure to protect against interference. This key, administered by a frequency coordinator such as ASHE, would ensure that equipment cannot be moved outside the hospital environment and transmit. In the 2390-2400 MHz band, which is used only lightly, Philips proposes allowing up to 20 milliWatts power without geographic restriction or need for an authentication key. In this band, cognitive technologies could protect primary operations while the MBAN devices could be used to monitor patients in homes, in ambulances, and at any other locations where the need exists.

To facilitate spectrum analyses, Philips has attached details of its studies at Appendix E. It also has provided information on the expected technical characteristics of MBAN devices at Appendix A. In Appendix C, Philips lays out methods of controlling MBAN devices to ensure failsafe compliance with the Commission's rules to avoid interference.

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COMMENTS OF PHILIPS HEALTHCARE SYSTEMS

Philips Healthcare Systems ("Philips") submits these comments to address spectrum for new Medical Body Area Network ("MBAN") systems proposed in the Notice of Proposed Rulemaking ("NPRM" or "Notice") in the above-captioned proceeding.[1] Philips strongly supports the proposed allocation of 40 MHz of spectrum at 2360-2400 MHz to enable this new class of wireless medical devices. Employing wireless devices in this spectrum to monitor patients is absolutely critical to achieving our national goals of improving patient care, creating electronic health records, and reducing healthcare costs as set forth by Congress earlier this year in the HITECH Act.[2]

As demonstrated by the results of technical analyses included in these comments, operation of the proposed devices in this spectrum can be accomplished with little chance of harmful interference to other users, and the alternative spectrum options are not feasible.

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[1] ET Docket No. 08-59, *Amendment of the Commission's Rules To Provide Spectrum for the Operation of Medical Body Area Networks*, Notice of Proposed Rulemaking, FCC 09-57, 24 FCC Rcd ____ (2009).

[2] *See Health Information Technology for Economic and Clinical Health Act* ("HITECH Act"), adopted as Title XIII of the American Recovery and Reinvestment Act of 2009, Pub. L. No. 111-5 (2009) ("ARRA"). *See also* http://healthit.hhs.gov.

Accordingly, Philips requests that the Commission promptly allocate the 2360-2400 MHz band on a secondary basis for MBAN subject to the regulatory requirements and interference safeguards discussed below.

Introduction

Philips, one of the largest suppliers of medical equipment in the United States, is a world leader in medical equipment design and manufacture. Philips operates in five main healthcare areas: healthcare information, diagnostic imaging systems, clinical solutions, customer services and home healthcare solutions. Our product lines include best in-class technologies in patient monitoring and remote telehealth monitoring as well as in radiology and cardiology enterprise imaging and information management, eICU, X-ray, ultrasound, magnetic resonance, computed tomography, nuclear medicine, PET, personal emergency response systems, and resuscitation products.

Philips is the world leader in patient monitoring equipment.[3] For over 25 years, Philips has been delivering solutions that acquire, analyze, and present patient data in ways that are meaningful for clinicians in the most challenging clinical areas. We provide clinical informatics and patient care solutions that help improve and save lives, lower the overall cost of healthcare, and simplify clinician workflow.

Background

Introduction of MBAN devices for wireless patient monitoring is an essential component to improving patient outcomes and lowering healthcare costs. Through low-cost, wireless

[3] F&S Market Research Report 2000 - 2008, based on the countries composing 90% of the world market (United States, Canada, France, Germany, Italy, Spain, United Kingdom, Belgium, Netherlands, Russia, Brazil, Mexico, Japan, China, India, Australia, Turkey and Malaysia).

devices, universal patient monitoring can be extended to most if not all patients in many hospitals. But this advance will occur only if the Commission allocates sufficient and suitable spectrum to enable inexpensive wireless devices to monitor multiple key parameters of patients. With such monitoring, changes in a patient's condition can be recognized at an early stage and appropriate action taken. Achieving this result can substantially improve the outcome for the patient *and* avoid the need for costly acute intervention measures. Patient care will be improved and substantial costs saved.

MBAN devices represent the appropriate technology to allow sensors to reliably and inexpensively collect multiple parameters simultaneously and relay the monitoring information wirelessly so that clinicians can respond rapidly. Allocating the requested spectrum for MBAN devices will foster production of low cost sensors that are key to monitoring systems that also often will include software based upon proven algorithms to identify trends and alert care providers to possible adverse changes earlier than possible through patient observation of individual parameters alone. This is the exciting promise of MBAN -- more efficient and accurate monitoring of multiple parameters so that intervention can be made at the earliest possible time. Quicker intervention saves lives, improves outcomes, and lowers costs by acting before conditions become life-threatening.

Allocating the Full 40 MHz of Spectrum at 2360-2400 MHz Will Lessen Interference Potential and Promote Device Innovation

Much of the Discussion in the Notice concerns the amount of spectrum required for operation of MBAN devices and whether spectrum bands other than that at 2360-2400 MHz

would be suitable.[4] Allocation of the full 40 MHz at 2360-2400 for MBAN provides the most effective solution to meet the medical need for MBAN devices. Alternatively, a 20 MHz exclusive primary allocation of contiguous spectrum in this same 2300-2400 MHz band would meet the need for MBANS devices. But such an exclusive allocation appears unlikely, so herein we focus our comments on MBAN devices sharing the 2360-2400 MHz band on a secondary basis.

The substantial analyses conducted by Philips Research Labs summarized in Appendix E attached to these Comments demonstrate that, with appropriate protection mechanisms, this spectrum can be shared by low-power MBAN devices with little chance for harmful interference to AMT in the 2360-2395 MHz band, amateur radio in the 2390-2400 MHz band, or radio astronomy in the 2370-2390 MHz band. The other spectrum options suggested in the Notice are so substantially inferior to the 2360-2400 MHz band for this purpose that MBAN devices would be unlikely to succeed for both cost and technical reasons, and the opportunity to benefit from better healthcare using these devices likely would be substantially delayed or lost.

The 2360-2400 MHz spectrum allows the best opportunity for coexistence with the primary users without harmful interference to those users or from those users to the MBAN devices if good spectrum management practices and appropriate technologies are utilized. It is in the clear public interest to allocate this spectrum on a secondary basis for MBAN devices to put to work this underutilized valuable natural spectrum resource. Usage by the primary users is compatible with very low power MBAN devices (1 milliwatt [mW] maximum effective isotropic

[4] Notice, *supra* Note 1 at ¶¶ 15-32.

radiated power [EIRP]) to be used indoors at hospital facilities in the 2360-2390 MHz band if modest exclusion zones are used to protect AMT receiver locations.

Furthermore, the record indicates scant use by AMT of the 2390-2395 MHz portion of the spectrum. This spectrum therefore should be joined with 2395-2400 MHz to allow the 10 MHz to be used for MBAN in-home and mobile devices with up to 20 mW EIRP. In the in-hospital environment we expect that the device duty cycle per patient will not exceed 25%. The duty cycle in the in-home environment, however, typically is expected to be less the 2%. This will allow MBAN devices in homes to achieve long battery life, even at higher output power. In Appendix D we describe the details for the home monitoring application, while in Appendix C we set out ideas for preventing unauthorized use when devices may be moved to a different location. In Appendix E, we address in detail the technical issues of both these proposed uses and demonstrate how such uses can be introduced into this spectrum without harmful interference.

It is emphasized that allocating the full 40 MHz of spectrum for MBAN devices ***improves*** coexistence with the incumbent primary users as compared with a smaller allocation. A full 40 MHz allocation maximizes opportunities to avoid interference to and from the primary users of the spectrum while accommodating substantial use for MBAN devices. The less spectrum allocated, the more difficult it will be to avoid interference, whereas the full 40 MHz of spectrum will maximize opportunities to avoid interference through frequency separation, support the coexistence of multiple and competitive MBAN networks, and provide the spectrum needed for future innovation.

The amount of spectrum also should be capable of supporting MBAN devices in high-density deployment cases. Philips envisions that in some cases, such as waiting areas of Emergency Rooms (ERs), elevator lobbies, preparatory areas for imaging services etc., multiple patients with active MBAN sensors could gather and frequency coordination and/or contention-based protocols would be required to coordinate the distributed MBAN operations to avoid interference among the MBAN devices. Frequency-hopping and listen-before-talk ("LBT") protocols are two popular unsynchronized coordination schemes that are suitable for MBAN applications. In a GE Healthcare analysis previously submitted, the performance of a frequency hopping based coordination scheme was studied and the conclusion was that approximately 18 MHz is required to support the co-existence of ten heavily loaded and mobile Body Sensor Networks ("BSNs") with acceptable packet loss probability. Therefore, in a shared environment "a 40 MHz allocation would provide sufficient bandwidth for MBAN devices utilizing contention based protocols to operate with sufficiently low packet error rate and without impact to primary radio service users."[5]

Coexistence Mechanisms Will Enable MBAN Devices to Efficiently Share Spectrum With Incumbent Primary Users

The three incumbent users of the 2360-2400 MHz spectrum are AMT, amateur radio, and radio astronomy. MBAN devices can successfully share the spectrum with each of the three services. In Appendix A to these Comments, Philips responds in more detail to the Commission's request to characterize the MBAN and AMT systems; in Appendix C Philips addresses device management controls; and in Appendix E Philips Research Labs discusses exclusion zones and device protection mechanisms. MBAN devices with cognitive and adaptive

[5] GE Healthcare *Ex Parte* Comments filed in ET Docket No. 06-135, December 27, 2007.

spectrum sensing will help to manage the spectrum in the most efficient manner, coupled with exclusion zones to protect incumbent AMT users.

Exclusion Zones. We agree that applying exclusion zones to MBAN devices operating in the 2360-2390 MHz band will protect AMT sites. We propose that by default, MBAN devices be permitted to operate unrestricted in the 2390-2400 MHz spectrum with up to 20 mW of power. Such devices would check for an authorization key before being permitted to access the lower 2360-2390 MHz band. If a key is available to the device it would be permitted access and limited to 1 mW in the lower band. Such an access key system could be implemented manually or automatically implemented through software.

Registration of hospitals with a coordinator, such as ASHE (the FCC-recognized coordinator for hospital use of WMTS spectrum), discussed below, would ensure that each requesting hospital is not within an exclusion zone. MBAN devices would obtain registration information to initiate authorized transmissions at the time of MBAN installation. The Coordinator would provide an electronic key for use by the MBAN devices tied to the hospital infrastructure that would authorize use of the 2360-2390 MHz spectrum. Devices that do not receive an authorization key could operate by default only in the unrestricted 2390-2400 MHz band.

Special provision should be provided in the rules to allow hospitals within an exclusion zone to coordinate with the affected AMT site. In this case frequency separation may be used to protect the AMT site. If no suitable spectrum could be defined, the MBAN devices would be restricted to the 2390-2400 MHz band by default. If a hospital has deployed MBAN devices and later a new AMT site is established so that the hospital now is within an exclusion zone, the

hospital would be informed through the coordinator and subject to the same restrictions as if it always had been within an AMT exclusion zone.[6] *See* Appendix C to these Comments concerning MBAN device management.

Through extensive independent analysis and simulation conducted by Philips Research Labs, we have concluded that an exclusion zone of 11.5 km maximum generously protects AMT sites under even the most challenging situations.[7] Our analyses demonstrate that operation of MBAN devices outside such proposed exclusion zones will not impact AMT link performance, even when large numbers of MBAN devices, such as 800, each transmit with a 25% duty cycle. The presence of MBAN devices does not present an increase in the AMT link data loss, therefore they will not impact test flight operations. Supporting analyses and additional details of our proposal are at Appendix E.

Protocols. MBAN devices will fully protect themselves operating on a secondary basis by deploying advanced radio technologies. Philips supports contention based protocols for MBAN devices. However, within the Commission's rules this should be defined only at a high level. A flexible definition allows greater capacity to manage evolving radio technologies.[8] Many available radio technologies already deploy such protocols, so selecting a specific protocol

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[6] We do not expect there to be a substantial number of large hospitals within AMT exclusion zones because most AMT site locations are outside major population areas.

[7] We suggest the measured distance for MBAN operation be defined from the center of the incumbent area of operation (the location of the AMT receiver station). For multiple incumbent sites in close proximity, the protected area would be defined by the intersection of circles from the center of each site.

[8] The MedRadio LBT definition is not appropriate for MBAN devices. The difference in duty cycle factors make this definition impractical for MBAN, where some applications require a more dynamic response to manage interference. Flexibility for device manufacturers will provide the flexibility needed to optimize devices for best application performance.

should be left to the industry and standards bodies such as the IEEE.[9] We fully expect that new, more effective protocols will be developed in the future. These additional methods also would be deployed as appropriate to protect other users. Examples are cognitive and adaptive spectrum sensing to find clear spectrum with LBT protocols, and error detection and/or error correction, CCA, and ARQ methods. If correction fails, the device could fall back to error detection (CRC on data) and search for clear spectrum.[10]

AMT. We propose that the potential for interference from MBAN devices to AMT receivers in the 2360-2390 MHz band be mitigated by utilizing exclusion zones, discussed above. Frequency coordination/frequency agility (frequency separation) would minimize even further the possibility of mutual interference between AMT systems and MBAN devices. A full 40 MHz allocation is critical to support MBAN operations in dense deployment scenarios with frequency separation requirements.

AFTRCC indicates that future AMT systems (iNet) would use high-power, omni-directional, uplink and downlink transmissions with a bandwidth of 2-20 MHz.[11] High-power, omni-directional uplinks would make it easier for MBAN devices to detect incumbent AMT users so that the devices can move off the AMT channel to avoid interference. In a worst case scenario, 20 MHz of the allocated spectrum may be occupied by an AMT link while 15-20 MHz

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[9] Standards bodies such as IEEE 802.15.6 (Body Area Network task group) are involved in creation of relevant standards. This is an appropriate place to define protocols.

[10] Systems are designed to comply with requirements of the Food and Drug Administration ("FDA") for wireless systems and are required to deal with the case of interference, such as clinical staff notification via system technical alerts. There also are suitable protocols used to handle data loss due to interference. Specific link management protocols should be managed by the industry to meet FDA guidance, and not be a part of the Commission's rules.

[11] AFTRCC *Ex Parte* Comments filed in ET Docket No. 08-59 (dated July 28, 2008).

of spectrum would be needed for MBAN operations under the most high-density deployment cases (*see* Appendix E). Consequently, a total of 35-40 MHz of spectrum will adequately support interference-free AMT and MBAN operations.

Even in the case that MBAN devices may not detect AMT operations, a full 40 MHz secondary allocation for MBAN would reduce the probability that an MBAN network would operate within an AMT channel, and therefore the full allocation will reduce the aggregated interference power into an AMT receiver. For example, if an AMT receiver has a bandwidth of 5 MHz and the total allocated MBAN spectrum is 40 MHz, then each MBAN network has a probability of 0.125 (5/40) of operating within the AMT channel. If there are 100 active MBAN networks in a hospital and they select their MBAN channels randomly (with a uniform distribution) and independently, then on average there would be 12.5 MBAN networks operating within any AMT channel. However, if the allocated MBAN spectrum is 30 MHz, there would be on average 16.7 MBAN networks operating within any AMT channel. A larger spectrum allocation therefore will reduce aggregated power within any AMT channel and is preferred.

Regarding interference from AMT transmitters into MBAN devices, spectrum sensing techniques can be utilized by MBAN devices to effectively detect in-band signals and frequency agility would enable an MBAN device to switch to a clear channel when an in-band signal is detected. The full 40 MHz spectrum allocation again plays a key role by providing sufficient spectrum for AMT and MBAN operations to coexist.

Amateur Radio. Amateur radio uses the 2390-2400 MHz band. Interference from MBAN devices to amateur radio is unlikely due to the low transmission power and low duty cycle for MBAN devices, geographic separation, and MBAN frequency agility. A 40 MHz

spectrum allocation would provide MBAN devices enough spectrum choices to avoid amateur operations. As the ARRL stated, "ARRL, does not, frankly, expect a significant amount of harmful interference to Amateur operations at 2390-2400 MHz from BSNs."[12]

Regarding interference from amateur radio operations to MBAN devices, spectrum sensing techniques utilized by the MBAN devices can effectively detect in-band amateur signals and frequency agility mechanisms can move an MBAN device's frequency to a clear channel whenever in-band interference is detected. A 40 MHz spectrum allocation would play a key role in this situation by maximizing chances that clear channels will be available.

Radio Astronomy. Radio astronomy use of the 2370-2390 MHz band is limited to a single radar located in Arecibo, Puerto Rico. Use of an exclusion zone is the most feasible method to protect this remote site. Also, the extraordinarily high radiated transmission power of the radio astronomy facility will make it easier for MBAN devices with spectrum sensing to sense the signal. Frequency coordination/frequency agility methods can be used to avoid interference and thereby improve the co-existence of MBAN and radio astronomy operations.

Other Spectrum Options for MBAN Devices are Not Feasible

In Appendix B attached to these Comments, Philips details the difficulty of using the other spectrum bands suggested in the Notice. The 2.4 GHz Part 15 band is in particularly heavy use at most hospitals, with multiple devices commonly used in the hospital environment as detailed in Appendix B. We note that high-powered ISM equipment regulated by the

[12] ARRL, the national association for amateur radio, Comments filed in ET Docket 08-59 (dated May 28, 2008).

Commission under Part 18 also is commonly found in hospitals, providing an additional source of interference concentration in addition to various Part 15 unlicensed devices.

The 5150-5250 MHz band is too costly, has high propagation loss, and high power consumption and therefore is unable to support the goals of low cost and long battery life for MBAN devices. The higher transmit power needed for 5 GHz devices would exceed the ability of the small batteries envisioned for the sensors to power the transmitters for the desired length of time. In addition to free space signal attenuation, propagation through the body also is a great challenge at 5 GHz . Researchers have observed up to a 56 dB body absorption loss, a further challenge to make a 5 GHz link meet MBAN requirements.

For example, available 802.11 a/b/g radio chips operating in the 5 GHz band have transmitter power consumption of 300mW (with -5dBm RF power) and receiver power consumption of 250mW. This is one of the lowest power consumption 5 GHz radio chips available. Additional power is needed to overcome increased propagation losses, so even higher peak power consumption at around 350mW will be necessary. The peak power requirement makes the power system expensive, and the required large capacity batteries are not suited for small disposable MBAN devices. Even with duty cycle management, the overall goals are not achievable because the peak power needs are so high. The clinical user needs multi-day battery life to make the MBAN use model achievable.

The comparison to 2.4 GHz technology is striking. The following 2.4 GHz IEEE 802.15.4 example demonstrates the suitability of the adjacent 2.3 GHz spectrum for MBAN devices and that this and similar technologies used at 2.4 GHz can be leveraged for MBAN. An IEEE 802.15.4 radio in the 2.4 GHz band has transmitter power consumption of 32mW, and the

receiver power consumption is 36mW. With duty cycle management, the goals and objectives of an MBAN device for power usage can be achieved. There are other low power radio technologies being used in the 2.4 GHz band that also can be leveraged.

In conclusion, developing a radio in the 5 GHz band for MBAN will not achieve the cost point needed for the envisioned low cost disposable solutions that can be achieved by devices operating at 2.3 GHz. The commercial volumes needed to achieve price goals are unlikely to be achieved at 5 GHz due to the physical propagation limitations and substantially higher costs.

The existing WMTS bands also are not suitable for MBAN devices. These bands are widely used in hospitals for incompatible uses and are subject to saturation by those uses. Large hospitals have hundreds of devices deployed and continue to expand.

The proprietary radio technology used in the WMTS spectrum also is expensive and not suitable for low cost MBAN devices. In a typical mid-size hospital, there may be 550 WMTS devices and 1600 MBANS devices (assuming 2 MBANS devices per patient average). WMTS typically can support 1000 devices. There just is not sufficient capacity to support existing telemetry applications and MBAN in the WMTS band. In addition, where capacity exists, WMTS will complement MBAN as a source for backhaul.

The 2300-2305 and 2395-2400 MHz proposal -- 10 MHz -- falls even shorter of meeting MBAN requirements. Because it is not contiguous spectrum, guard bands would be required that would further lessen the capacity of this spectrum.

Bandwidth of 5 MHz Should be Permitted

We propose limiting the permitted bandwidth to 5 MHz, rather than the proposed 1 MHz, subject to the same 1 mW EIRP power limit. This is a new service where one can expect competing innovative equipment. It is important to allow flexibility for future radio technologies. The bandwidth limits should be based on limiting interference potential. Given the bandwidth of AMT and amateur signals, no purpose is served by limiting MBAN signals to 1 MHz as proposed. So long as the power limit within an established bandwidth is observed, MBAN signals should be permitted up to 5 MHz. In the neighboring 2.4 GHz band, some technologies use bandwidths of up to 3 MHz, and there are well-known technical advantages to using wider bandwidths.

A 1 MHz bandwidth limit would be too restrictive because it eliminates many existing radio technologies that can be leveraged for use in MBAN devices. Allowing a bandwidth up to 5 MHz allows for future evolution of technology. Higher bandwidth also would allow MBAN devices to use a lower duty cycle and support higher data rates that can accommodate future medical monitoring devices. In more critical care settings, there is a need for more streaming real-time data and improved link robustness. A greater bandwidth will allow more spreading gain, making these links more robust while supporting more clinical data throughput. This greater bandwidth also will allow more applications and use a shorter transmit duty cycle, thereby reducing power consumption and promoting more efficient spectrum sharing. Therefore a 5 MHz bandwidth limit should be adopted instead of the proposed 1 MHz. This is discussed further in Appendix E.

Licensing and Frequency Coordination

Philips suggests that the Commission's Part 95 licensing scheme is appropriate for MBAN authorization and should leverage the frequency coordination process established for WMTS operation to deal with hospital sites that fall inside the exclusion zone. However, improved control methods could be implemented to ensure that only authorized transmissions are made. An example of such an approach to device management is described in Appendix C.

Philips envisions a process in which ASHE is used as the coordinator with AFTRCC, NTIA, and FCC. ASHE would be the single point of contact for hospitals and medical device manufacturers. Hospitals in the exclusion zone will by default operate on the 10 MHz of spectrum at 2390-2400 MHz. If that spectrum is not sufficient coordination through ASHE would be initiated. There should be registration of each site as is done with WMTS. It is a well established process that manufacturers and hospitals understand and have trained resources to manage. Today, the WMTS locations are registered with ASHE and this also can work in the MBAN case although only a subset of the information used to manage WMTS would be sufficient to manage coordination activities for MBAN. Unlike WMTS, there is no need to register specific frequencies or numbers or type(s) of devices. Only the site location would need be registered for MBAN.

In the case of a new AMT site, the coordinator's database could be checked to see if a hospital is located within the exclusion zone. This provides an opportunity for AMT sites to be defined to avoid a conflict, but if that is not possible, if a hospital has deployed MBAN and the hospital is now in an exclusion zone the hospital would be informed through ASHE of the new restrictions. In this case, frequency coordination can be completed through ASHE to establish frequency separation to protect the AMT site. If no spectrum could be defined in the AMT

spectrum to establish frequency separation, the site would be restricted to the 10 MHz of spectrum that is not used by AMT. This is expected to be a very rare case, as most AMT sites are outside major population centers. Hospitals near these areas consequently are small, serve small populations and so most likely have small numbers of MBAN devices deployed.

Miscellaneous Provisions

Inspections and Disclosure. We agree that the Commission should have a provision to inspect MBAN transmitters to resolve interference situations. We also have no objection to including disclosure statements that devices must accept interference from primary users and not cause harmful interference to primary users. Manufacturers should be permitted to provide such disclosures in user documentation if the MBAN device is too small to carry a full disclosure statement. The proposed additional marketing limitations proposed also are acceptable.

Unwanted Emissions. The general limits that are applicable to Part 15 devices used in the adjacent unlicensed band are acceptable for MBAN operation. There is a critical need to leverage radios from the adjacent 2.4 GHz spectrum so equivalent emission rules are desirable.

Frequency Stability. MBAN devices can operation with a frequency stability limit of +/- 100ppm.

Antenna Locations. The spectrum from 2360-2390 MHz (AMT band) can be restricted to indoor use in healthcare facilities. Doing so will allow for exclusion zone management. For the spectrum 2390-2400 MHz, no antenna location restriction should apply. In the 2390-2400 MHz band, outdoor transmitting antennas should be permitted to allow patient monitoring in homes, ambulances, and other locations.

RF Safety. We agree that the definition of MBAN devices should be as portable devices worn by humans and that the devices should be subjected to the RF exposure rules defined in the Commission's Rules. The low duty cycle of MBAN devices produces RF exposure well under the FCC SAR limits as well as all other international exposure limits. With 25%, duty cycle exposure is 0.25mW. MBAN in the home with 20mW also will use a very low duty cycle (example: <2%, a few seconds of transmission every hour). This produces RF exposure that is well below the SAR limits as well as other international exposure limits.

Conclusion

For the reasons stated above and in the Appendices attached hereto, Philips supports a 40 MHz allocation of spectrum in the 2360-2400 MHz range for MBAN. Allocating all of this spectrum on a secondary basis will lessen interference potential and promote innovation. Implementation of coexistence mechanisms will enable MBAN devices to efficiently share spectrum with incumbent primary users.

Respectfully submitted,

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APPENDIX A

Response to FCC NPRM Request for Characteristics of MBAN and AMT Systems

The following parameters for MBAN systems should be used, as appropriate, to address further technical analyses.

MBAN Characteristics

- **What baseband data rate should be assumed for MBAN devices?**

  - For in hospital, monitoring data rates of 250 Kbps to 3 Mbps are expected, depending on the application, with most devices requiring data rates between 250 Kbps to 1 Mbps.
  - For home monitoring in the 2390-2400 MHz band, where the requirement is for longer ranges, lower data rates are expected. For example, a typical data rate could be 31.25 Kbps, which is used in our analysis in Appendix E.

- **What frequency reuse criteria will be employed?**

  - With the full proposed 40 MHz spectrum allocation, frequency reuse (or spectrum sharing, or self-coexistence) can be achieved with various contention based protocols. Any contention based protocol that complies with FCC regulations and MBAN requirements can be used to achieve frequency reuse.

- **What modulation efficiency could be achieved (e.g., bits per second per hertz)?**

  - For the proposed 5 MHz bandwidth limit, no larger than 1 bit/s/Hz modulation efficiency is predicted.

- **What duty cycle limits are typically used for MBAN applications**?

  - 25% maximum in hospital use; home use will be significantly lower, estimated at < 2%.

- **What emission bandwidths are required for the medical applications envisioned?**

  - The proposed 5 MHz emission bandwidth limit would provide needed flexibility to accommodate future innovation..

- **What maximum EIRP is required for the medical applications envisioned**?

  - 1 mW in the 2630-2390 MHz band and 20 mW in the 2390-2400 MHz band.

- **What bandwidth, noise figure, antenna gain and gain pattern should be used in assessing interference into MBAN receivers?**

  - Bandwidth would depend on the data-rate requirement of the particular MBAN application. For high rate applications (e.g., 250 kbps and beyond), the bandwidth could

be 3~5 MHz. For low-rate applications, the required bandwidth could be lower. Typical systems may use a dipole antenna or omni-directional one. Body worn devices would likely use a small chip antenna in the dipole class. If a MBAN device were to use a higher gain antenna, it would be required to comply with the EIRP power limits defined above. For the purpose of interference analysis, we suggest the following parameters: omni-directional antenna with 0 dBi gain, and 6-10 dB noise figure.

- **What interference criteria are appropriate for evaluating interference into MBAN receivers?**
    - Application bit error rate < $10e^{-3}$ for non-critical monitoring; for more critical monitoring, the application bit error rate should be < $10e^{-6}$.

AMT Characteristics

- What emission bandwidths are used by the aeronautical telemetry services?
- What maximum EIRP is used by typical aeronautical telemetry systems?
- What bandwidth, noise figure, antenna gain and gain pattern should be used in assessing interference into AMT receivers?
- What interference criteria are appropriate for evaluating interference into AMT receivers?

Note: In the Philips' simulations described in Appendix E, the AMT parameters were used as defined in the ITU-R document for:

1. AMT transmitter: antenna gain pattern, power
2. AMT link, free space path loss
3. AMT receiver: bandwidth, central frequency, directional antenna gain pattern, minimum SNR required, acceptable I/N ratio, height

To have better modeling and interference analyses, as well as to design MBAN devices with the least potential for harmful interference into AMT receivers, AMT parties should provide the following additional information about AMT systems:

1. AMT TX: modulation, coding, spreading, data rates, packet size, burst transmission/continuous transmission, maximum ARQ retransmission number, diversity scheme
2. AMT tracking antenna: tracking mechanism, tracking performance
3. AMT receiver, performance requirements (BER, SNR), noise figure, diversity scheme, practical sensitivity parameters

APPENDIX B

Why the 2360-2400 MHz Spectrum is Needed for MBAN Devices

Review of other spectrum for MBAN (2.4 GHz ISM/Part 15 & 5.15-5.25 GHz Part 15)

2.4 GHz ISM band already is saturated by higher-powered devices (typically 100 mW) used in hospitals, and will not support the growth of lower-powered (1 mW) MBAN devices

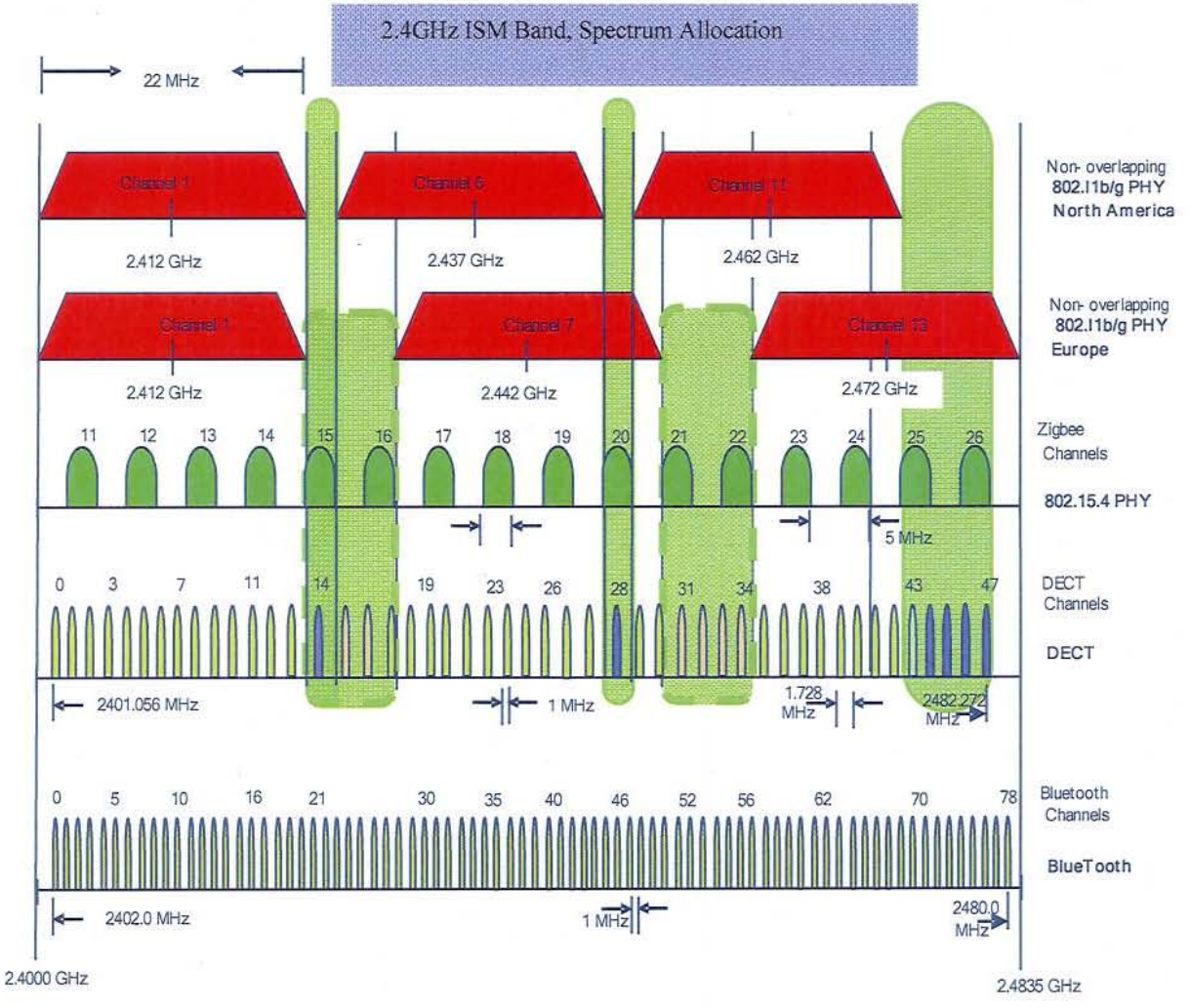

Figure 1 2.4 GHz ISM band spectrum allocation

2.4 GHz Devices Found In Typical Hospitals

1.	VoIP Phones [802.11 b/g]	[RF level 100mW]
2.	Access Points [802.11 b/g]	[RF level 100mW]
3.	Doctors' Laptop PCs with 802.11 b/g	[RF level 100mW]
4.	Wireless Phones [Frequency Hoppers]	[RF level 100mW]
5.	Bluetooth devices [Frequency Hoppers], public devices	[RF level 100mW]
6.	Wireless PC devices (Mouse, etc) in 2.4 GHz band	[RF level 100mW]
7.	Bluetooth medical devices	[RF level 100mW]
8.	Medical, Patient Bedside Monitors [802.11 b/g]	[RF level 100mW]
9.	Telemetry in 2.4 GHz band, medical application	[RF level 100mW]
10.	Medical devices using 802.15.4 (Zigbee)	[RF level 1mW]
11.	Ultrasound Machines with wireless interface	[RF level 100mW]
12.	Defibrillators with WiFi interface	[RF level 100mW]
13.	PDA, Clinician carried device [802.11 b/g]	[RF level 100mW]
14.	Doctors' and Nurses' Internet enabled Cell Phones	[RF level 100mW]
15.	Device location systems [802.11 b/g]	[RF level 100mW]
16.	RF-ID devices for equipment tracking	[RF level 100mW]
17.	Microwave Ovens	[RF level >100mW]
18.	Public Internet Access	[RF level 100mW]
19.	Devices using 802.11n (MIMO)	[RF level 100mW]
20.	The list continues to grow with new applications	

This spectrum is too heavily used to support the high number of MBAN devices fully, especially for applications that need high quality of service. MBAN devices would be overwhelmed by higher power ISM equipment and Part 15 devices that are in close proximity in a hospital environment. For example, if an MBAN system is designed with 802.15.4 radio technology, then to support real-time monitoring only channels that are orthogonal to WiFi channels could be used. This would provide only about 10.4 MHz of total spectrum for MBAN applications, but use of that spectrum would conflict with Zigbee systems that also often are deployed in hospitals. Also, this limited spectrum could not support multiple MBAN vendors using similar or other technologies.

- 5.150 - 5.250 GHz band devices consume too much power for viable MBAN devices and spectrum already has substantial use in hospitals that is increasing.

  5 GHz Devices Found In Typical Hospitals

  1. VoIP Phones, 802.11a
  2. Access Points, 802.11a/n
  3. Doctors' Laptop PCs with 802.11a
  4. Patient Bedside Monitors [802.11a]
  5. PDA, Clinician carried devices [802.11a]

The spectrum has high propagation and body losses. The losses result in the radio technologies used in this spectrum consuming too much power to implement viable MBAN devices.

- Capacity in 2360-2400 MHz band

MBAN devices require the full 40 MHz allocation with secondary user status within AMT band.

· Allows room for MBAN devices to avoid interfering with AMT sites.
· Allows for innovation in medical parameters that can be supported
· Enables monitoring technologies that will reduce cost and improve health outcome.
· Allows competitive multiple medical vendors to share spectrum effectively and reduce costs
· Allows use of multiple radio technologies

APPENDIX C

MBAN Device Management

Philips suggests that some form of electronic control be implemented to enable access to the 2360-2390 MHz spectrum. This will strengthen device management, prevent unauthorized use of AMT spectrum, and enforce the exclusion zone. Our suggestion is to use an enhanced form of the WMTS band management process.

The following is an example of what can be done to manage devices:

- MBAN devices could use an access key to enable authorized transmission in the 2360-2390 MHz band. The access key could be tied to the hospital site registration process to be managed through a coordinator, such as ASHE (the WMTS band coordinator). Discussions with ASHE indicate this approach is viable. The access key would be used in the devices located at hospitals and not in the patient device.
- In this process the coordinator would maintain a registration database (as it does for WMTS), and critically, would maintain AMT site location and exclusion zone coordinates. Hospitals that are located outside the exclusion zone would be provided with an access key.
- Without an access key, by default MBAN devices could operate only in the unrestricted spectrum (2390-2400 MHz). Thus in the 2360-2390 MHz portion of the spectrum adequate control would exist to prevent operation of devices outside of hospitals and within hospitals in exclusion zones.
- The simplest possible control mechanisms should be implemented to control system costs and ease process management.
- The process could handle a variety of system configurations, including standalone MBAN networks that are not network connected. In such a case the coordinator device would activate access to the 2360-2400 MHz band upon manual entry of an access key.
- A mechanism would be utilized to protect against unintentional movement of a MBAN device from an authorized hospital site. For example, if an MBAN device did not receive a beacon signal from its coordinator then it would stop transmissions in the 2360-2400 MHz band. This would be part of the listen-before-talk (LBT) or other protocol.
- The process described above is only one possible solution. Other methods are possible. The Commission's rules should be general and prescriptive in ensuring electronic controls to automatically protect the 2360-2400 MHz band. This would allow manufacturers to innovate satisfactory solutions and to create new solutions as technology improves.

Note: ASHE is the FCC-designated frequency coordinator for WMTS. Comsearch is ASHE's technical partner. ASHE should be considered for the MBAN frequency coordinator for the following reasons:
1) leadership and success in WMTS coordination;
2) connection to and representation of hospitals where MBAN will be deployed;
3) ability to easily leverage existing WMTS registration framework to accommodate MBAN devices; and
4) ASHE's issue advocacy programs would help reach all potential MBAN stakeholders.

APPENDIX D

Home Monitoring Compared to Hospital Monitoring

Home monitoring is different than monitoring in a hospital. Home monitoring will become a more important part of healthcare in the future as a key means to lower medical costs. A detailed analysis of the home link case is in appendix E. The 2390-2400 MHz spectrum is well suited to home monitoring.

- The dominant home use case is monitoring for patient adverse events and a periodic collection of data from patients in a home environment.
- Home patients may not be critically ill, but may have an adverse event that can become critical, so monitoring information must be reliably communicated to the remote monitoring facility
- Patients need to have full mobility within their homes. To keep cost down it is desirable to use only a single hub device in a home to achieve adequate coverage. For these systems to be viable equipment cost must be minimized.
- Home monitoring is greatly enhanced if the spectrum is not competing with a plethora of other permit-by-rule Part 15 devices.
- To handle the worse conditions, higher power is needed to allow patient mobility and to cope with any adverse event that may cause a patient to fall on the transmitter, causing significant signal attenuation. Without extra power multiple hub devices throughout the home would be required, driving up monitoring cost.
- The 2390-2400 MHz spectrum is next to the ISM band and suffers from excess noise from ISM devices, so additional power is needed to achieve a reliable link budget.
- For these reasons, a power limit of 20mW (13dBm) is appropriate for in-home monitoring devices (only). These MBAN devices could utilize power level control to minimize any interference potential.
- The home monitoring case is mostly an event driven transmission, with very low duty cycle. We can expect systems to have a duty cycle <2%, greatly reducing the chance of interference.
- The described architecture of a MBAN system can achieve the needed reliability even as a secondary status with advanced cognitive methods applied to the basic management of the device spectrum. This would allow leveraging the technology and driving up volumes to further reduce cost.

APPENDIX E

Engineering Analysis of Medical Body Area Networks

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1. INTRODUCTION

In this Appendix Philips presents engineering analyses and simulation results in support of its conclusion that the FCC should allocate on a secondary basis the entire 2360-2400 MHz bandwidth for MBAN. Doing so will maximize opportunities to avoid interference to and from the primary users of the spectrum while providing for substantial use of MBAN devices.

The need for allocating the full 40 MHz of spectrum for MBAN devices is explained in Section 2. Coexistence with incumbents (AMT, amateur radio and radio astronomy) as well as self-coexistence is shown to be improved with the full 40 MHz allocation as compared to a smaller allocation.

Section 3 contains a detailed simulation analysis of the size of exclusion zones that will adequately protect AMT systems in a variety of environments (urban, suburban and rural). This analysis includes the effects of different bandwidths for MBAN devices.

Link budget analyses are presented in Section 4. These analyses demonstrate the required transmitter power for in-hospital body-area networks in the 2360-2390 MHz band and for home healthcare applications in the 2390-2400 MHz band.

In Section 5 simulations and reasons are presented for allowing bandwidths of up to 5 MHz for MBAN devices, rather than limiting MBAN devices to the 1 MHz bandwidth proposed by the Commission.

Finally, Section 6 concludes with a summary of Philips' recommendations.

2. ALLOCATING THE MAXIMUM 40 MHZ OF SPECTRUM IS NECESSARY TO LESSEN INTERFERENCE POTENTIAL AND PROMOTE DEVICE INNOVATION

Philips supports an allocation of the full 40 MHz. The full amount of spectrum requested will maximize opportunities for the MBAN and AMT systems to avoid interference through frequency separation, support the co-existence of multiple MBAN networks, and provide the spectrum needed for future innovation.

2.1 40 MHz of spectrum, together with co-existence mechanisms, will enable MBAN devices to efficiently share spectrum with incumbent users without causing interference.

Allocations for incumbent users in the 2360-2400 MHz band are:

- Amateur Radio (2390-2400 MHz)
- Aeronautical Telemetry (AMT) (2360-2395MHz)
- Radio Astronomy (2370-2390MHz)

2.1.1 Co-existence of MBAN devices and Amateur Radio in the 2390-2400 MHz band

Interference from MBAN devices to amateur radio is unlikely due to the low transmission power and low duty cycle for MBAN devices, geographic separation, and MBAN frequency agility. A 40 MHz spectrum allocation would provide MBAN devices enough spectrum choices to avoid amateur operations. As the ARRL stated, "ARRL, does not, frankly, expect a significant amount of harmful interference to Amateur operations at 2390-2400 MHz from BSNs". [1]

Regarding interference from amateur radio operations to MBAN devices, spectrum sensing techniques that can be utilized by the MBAN devices can effectively detect in-band amateur signals and frequency agility mechanisms would move an MBAN device's frequency to a clear channel whenever in-band interference is detected. A 40 MHz spectrum allocation would play a key role in this situation by maximizing chances that clear channels will be available.

First, a 40 MHz allocation would provide enough spectrum for MBAN devices to avoid possible interference. For example, fast-scan TV and high-rate data modes of amateur radio use at least a 3 MHz bandwidth and often use bandwidths of 6 MHz. This would require at least 10 MHz of spectrum (*e.g.*, to provide a 3 MHz bandwidth MBAN channel or 2 to 3 1 MHz bandwidth MBAN channels outside the used amateur radio spectrum) for out-of-healthcare-facility MBAN operations. A 40 MHz allocation, with a 10 MHz band allocation for out-of-healthcare-facility use, would meet this requirement. Moreover, such an allocation would provide enough spectrum for in-healthcare-facility MBAN operations, where a higher device density is foreseen. Even with both an AMT link and amateur radio operations to be protected simultaneously, a 40 MHz allocation most likely would provide at least 14 MHz of spectrum for operation of MBAN devices (assuming 20 MHz AMT bandwidth and 6 MHz amateur radio bandwidth).

Second, a 40 MHz allocation makes it possible to use a larger channel bandwidth, such as 3 MHz per channel, for MBAN operations. A wider channel bandwidth can significantly enhance MBAN link performance and thereby improve immunity to in-band interference. With properly designed spectrum spreading and/or channel coding schemes, a high link margin can be achieved. Based on the link margin analysis in Section 4, it is reasonable to assume that a link margin of at least 10 dB can be achieved in typical use cases. Such a 10 dB link margin would enable MBAN devices to tolerate an in-band interference signal with a power 9.54 dB higher than the noise power (e. g. -101 + 9.54 = -91.46 dBm interference power, -101 dBm is the noise power for the case of 2 MHz bandwidth and a 10 dB noise figure) . It is feasible to detect an in-band interference signal with a power 9.54 dB higher than the noise power based on current spectrum

sensing techniques. Therefore, when the amateur radio interference is strong enough to be sensed (e.g. at least 9.54 dB stronger than the noise power), MBAN devices can detect it and switch to another frequency to avoid interference. When amateur radio interference is too weak to be detected (e.g. less than 9.54 dB plus the noise power), the 10 dB link margin will enable MBAN devices to still maintain normal operations within the current channel with guaranteed QoS performance. Because of the extremely low power of the MBAN device it is extremely unlikely that an amateur operation with that signal level would detect the MBAN device.

2.1.2 Co-existence of MBAN devices and AMT radios in the 2360-2390 MHz band

The potential for interference from MBAN devices to AMT receivers in the 2360-2390 MHz band would be mitigated by the use of exclusion zones (geographic separation). Frequency coordination/frequency agility (frequency separation) would minimize even further the possibility of mutual interference between AMT systems and MBAN devices.

A 40 MHz allocation is critical to support MBAN operations in dense deployment scenarios with frequency separation requirements to protect AMT operations. AFTRCC has indicated that future AMT systems (iNet) would use high-power, omni-directional, uplink and downlink transmissions with a band width of 2 - 20MHz.[2] A high-power, omni-directional uplink would make it easier for MBAN devices to detect incumbent AMT users so that the devices can move off the AMT channel to avoid interference. In a worst case scenario, 20 MHz of the allocated spectrum may be occupied by an AMT link while 15~20 MHz of spectrum would be needed for MBAN operations under the most high-density deployment cases, as analyzed in the following section. Therefore a total of 35~40 MHz spectrum is needed to adequately support interference-free AMT and MBAN operations.

Even in the case that MBAN devices are not able to detect AMT operations, a larger spectrum allocation would reduce the probability that an MBAN network would operate within an AMT channel, and therefore a larger allocation will reduce the aggregated interference power into an AMT receiver. For example, if an AMT receiver has a bandwidth of 5 MHz and the total allocated MBAN spectrum is 40 MHz, then each MBAN network has a probability of 0.125 (5/40) to operate within the AMT channel. If there are 100 active MBAN networks in a hospital and they select their MBAN channels randomly (with a uniform distribution) and independently, then on average there would be 12.5 MBAN networks operating within the AMT channel. However, if the allocated MBAN spectrum is 30 MHz, there would be on average 16.7 MBAN networks operating within the AMT channel. A larger spectrum allocation therefore will reduce aggregated power within any channel and is preferred.

Regarding interference from AMT transmitters into MBAN devices, spectrum sensing techniques can be utilized by MBAN devices to effectively detect possible in-band signals and frequency agility would enable an MBAN device to switch to a clear channel when an in-band signal is detected. The 40 MHz spectrum allocation again plays a key role here, as described in the above section, by providing sufficient spectrum for amateur radio, AMT and MBAN to coexist.

2.1.3 Co-existence of MBAN devices and radio astronomy radios in the 2370-2390 MHz band

Radio astronomy use of this band is limited to the S-band radar located in Arecibo, Puerto Rico. Therefore, use of an exclusion zone is a feasible method to protect the remote site. Also, the extraordinary radiated transmission power of the radio astronomy facility makes it easier for MBAN devices with spectrum sensing to sense the signal. Frequency coordination/frequency agility methods can be used to avoid interference and thereby improve the co-existence of MBAN and radio astronomy operations.

2.2 40 MHz spectrum allocation is needed to support MBAN network co-existence in high-density deployment scenarios

The amount of spectrum allocation should be capable of supporting MBAN operations with simple radios in high-density deployment cases. Philips envisions that in some cases, such as waiting areas of Emergency Rooms (ERs), elevator lobbies, preparatory areas for imaging services etc., multiple patients with active MBAN networks could gather together and frequency coordination and/or contention-based protocols would be required to coordinate the distributed MBAN operations in order to avoid interference among the MBAN devices. Frequency-hopping and listen-before-talk protocols are two popular unsynchronized coordination schemes that are suitable for MBAN applications. In a GE Healthcare analysis previously submitted the performance of a frequency hopping based coordination scheme was studied and the conclusion was that approximately 18 MHz is required to support the co-existence of ten heavily loaded and mobile BSNs with acceptable packet loss probability Therefore, “a 40 MHz allocation would provide sufficient bandwidth for MBAN devices utilizing contention based protocols to operate with sufficiently low packet error rate and without impact to primary radio service users”.[3]

The following analysis considered the performance of another popular contention-based protocol, listen-before-talk or CSMA (channel sensing multiple access) under a wireless ECG MBAN scenario. The ECG MBAN network studied here has a star topology, shown in Figure 1, and consists of a Multi-lead ECG sensor, a SpO2 sensor, and a hub device. The assumed traffic patterns are:

- ECG data: 96 kbps => 1 packet per 8ms, 111 bytes/packet (with 15 bytes PHY/MAC overhead, based on IEEE 802.15.4 packet structure)
- SpO2 data: 1.76 kbps => 1 packet per 0.5s, 125 bytes/ packet (with 15 bytes PHY/MAC overhead)
- Command data : one packet per 30s, 133 bytes/packet (with 15 bytes PHY/MAC overhead)

The CSMA/CA scheme adopted in IEEE 802.15.4 non-beacon mode is one of the proven listen-before-talk schemes and is used here to study the co-existence performance. Some parameters used are:

- 802.15.4 packet structure: 15 byte overhead (including PHY and MAC)
- Maximum back-off number N_bo = 5
- Contention window size: fixed to 127

- Error free transmission (reasonable assumption considering low bit error rate requirement)
- Two raw PHY data rates studied: 1 Mbps and 2 Mbps
- No ACK to simplify the analysis

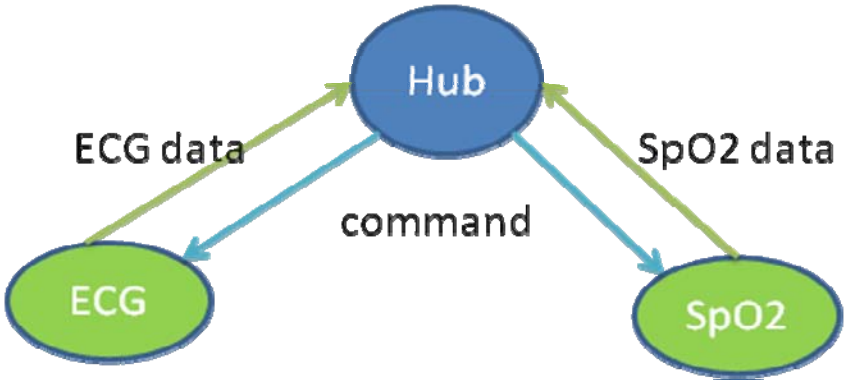

Figure 1: Star topology of an ECG MBAN

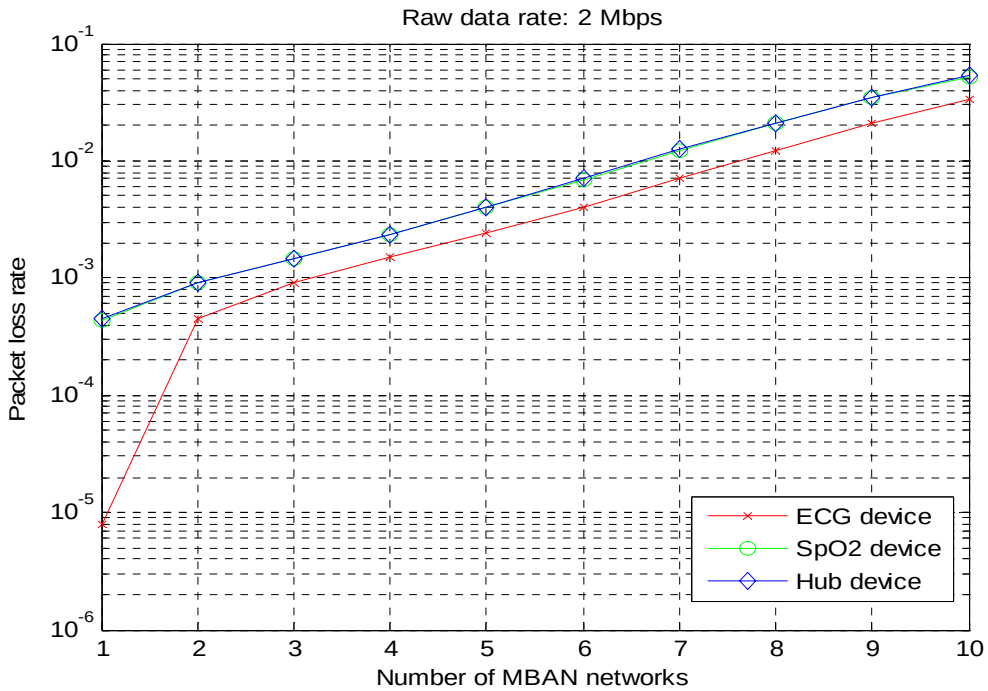

Figure 2: Packet loss rate performance with 2 Mbps raw data rate

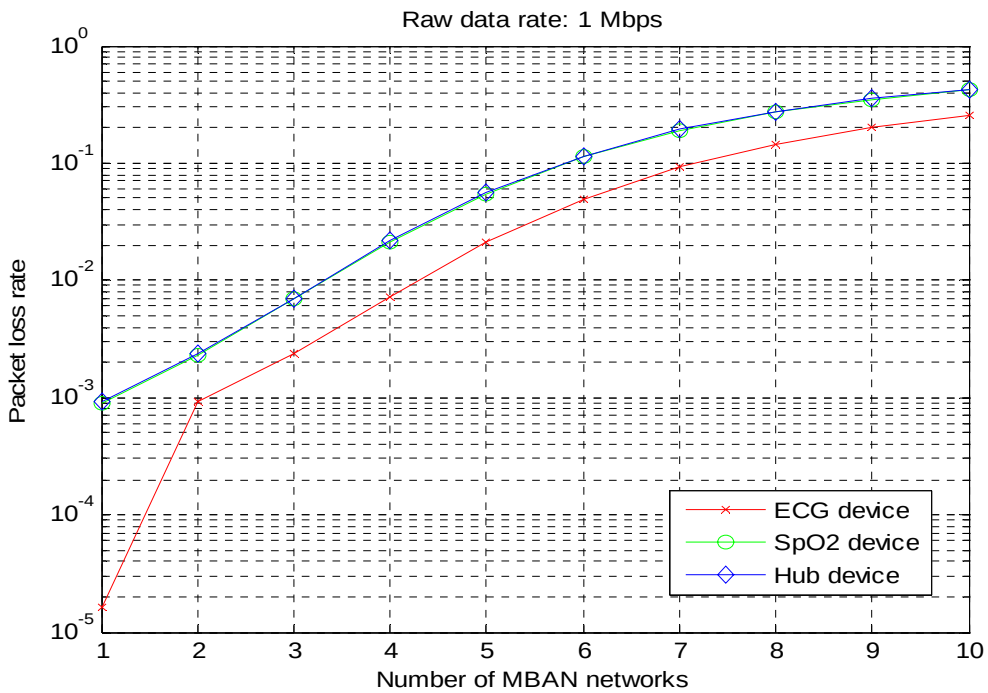

Figure 3: Packet loss rate performance with 1 Mbps raw data rate

The analysis is based on the results in [4]. Here we assume that a packet loss rate, **which is caused only by collisions among multiple MBAN devices**, of no larger than 10^{-3} is acceptable for MBAN applications. This is a reasonable performance criteria considering the importance of medical data in high acuity applications.

The above figures demonstrate that if the physical layer raw data rate is 1 Mbps, then one channel can support only one MBAN network. If two MBAN networks co-exist in the same channel, the packet loss rate of a hub device or SpO2 device would exceed 10^{-3}. Therefore, to support ten ECG MBAN networks, 10 non-overlapping channels are required. To achieve 1 Mbps with simple radio technology, the channel bandwidth should at least 1 MHz (for GFSK, 1.3 MHz for O-QPSK). Therefore, at least 10 MHz spectrum would be needed. Taking into consideration the guard band at each edge of the spectrum, approximately 12-15 MHz of spectrum would be required.

If the physical layer raw data rate is 2 Mbps, then one channel can support at most two MBAN networks. If more than two MBAN networks exist on the same channel the packet loss rate of a hub device or SpO2 device would be higher than 10^{-3}. Therefore, to support ten ECG MBAN networks, 5 non-overlapping channels are required. To achieve 2 Mbps with simple radio technology, the channel bandwidth should be at least 2 MHz (for GFSK, 2.6 MHz for O-QPSK). Therefore, at least 10 MHz of spectrum would be needed. Taking into consideration the guard band at each edge of the spectrum, approximately 12-15 MHz spectrum would be required.

Based upon these analyses, it is concluded that, "a 40 MHz allocation would provide sufficient bandwidth for MBAN devices utilizing contention based protocols to operate with sufficiently low packet error rate and without impact to primary radio service users" is also true for devices utilizing listen-before-talk based contention-based protocol.

For home applications, a 10 MHz bandwidth is sufficient to support at least 2 MBAN networks, even if a 6 MHz amateur radio signal is protected.

In summary, a 40 MHz allocation, with 10 MHz for out-of-healthcare-facility use, is sufficient to support multiple MBAN co-existence with currently available contention-based protocols.

2.3 A Contiguous 40 MHz spectrum allocation would provide flexibility for future MBAN innovations

An allocation of 40 MHz of contiguous spectrum would benefit future MBAN innovations, which may require low cost, lower power consumption, higher data rate, or other features. In particular, a contiguous spectrum allocation would simplify MBAN radio RF design and therefore reduce cost and power consumption.

3. EXCLUSION ZONES FOR AMT PROTECTION

The use of exclusion zones is a feasible and practical means to prevent interference from MBAN devices to incumbent AMT operations in the 2360-2390 MHz band. The statistical methodology proposed by GEHC is reasonable while the AFTRCC methodology is impractical. An 11.5 km radius generously protects AMT sites.

With regard to analytic methodology, the statistical analysis or Monte Carlo technique is a feasible methodology to analyze the potential for interference from MBAN systems to an AMT receiver while the minimum coupling loss (MCL) approach or worst-case analysis is pessimistic and impractical. Due to the random nature of wireless communication systems (propagation environment, TX/RX relative position, TX/RX antenna orientations, interference source distribution, etc.), it is very difficult, if not impossible, to calculate an accurate estimate of the co-existence performance of wireless systems under real, time-varying environments. The Monte Carlo technique, which is a statistical analysis method, is a powerful tool for such problems and has been widely used by both academia and industry, including by regulatory and standardization bodies such as IEEE, ITU, CEPT, OFCOM and FCC, to evaluate co-existence performance of wireless systems. The results provide a reasonable assessment of co-existence interference to enable engineers to improve spectrum usage efficiency while guaranteeing wireless system performance. At the same time, the minimum coupling loss (MCL) approach evaluates the co-existence performance based solely on the worst case, which has an exceedingly low probability of occurrence. Therefore, the MCL approach is too conservative and usually results in poor spectrum usage efficiency. The Monte Carlo method, by contrast, is a viable tool for studying MBAN/AMT co-existence performance and should be used.

Philips has conducted extensive simulations based on the Monte Carlo method to evaluate the interference potential of MBAN systems to AMT receivers. Our results are summarized as follows:

- An exclusion zone with a radius of 11.5 km protects AMT services:

    - Random relative geographic locations of AMT receivers and MBAN networks mitigates the effect of interference due to the directional pattern of the AMT receiver antenna.
    - Large MBAN bandwidth (40 MHz) mitigates the effect of interference.
    - Extra wall attenuation in the indoor scenarios (e.g. in-hospital applications) mitigates the effect of interference.
    - Duty cycle limits reduce the aggregated power at the AMT receiver front-end.

- Simulation results show that there is no obvious performance difference, in terms of the achieved AMT signal-to-interference-plus-noise (SINR), between a 1 MHz bandwidth MBAN system and a higher bandwidth (in our simulation, 2, 3, and 5 MHz) one.

    - Since the AMT signal has a wide bandwidth (up to 20 MHz), there is no obvious difference between a 1 MHz MBAN signal and a higher bandwidth MBAN signal at an AMT receiver in terms of in-band power.
    - In reality, a wider bandwidth with a fixed transmission power limit (1mW) is favorable to incumbent users due to its lower power spectral density and more white-noise-like property.

- In conclusion, we strongly believe that a 11.5km exclusion zone radius will fully protect AMT receivers from interference from MBAN operations.

We developed a Matlab program to simulate the distribution of random interference from MBAN devices to an AMT receiver. The simulation parameters/assumptions used are listed below:

- AMT Transmitter – based on ITU-R M1459

    - **10 watt (40dBm) transmission power**
    - **Omni-directional transmit (TX) antenna with random antenna gain and the gain distribution** is given in Equation (2) of ITU-R M1459
- AMT Receiver – based on ITU-R M1459

    - **Directional receiver antenna (RX) with the composite pattern defined in Equation (1) of ITU-R M1459 (41.2 dBi maximum gain with a narrow beam)**
    - **Height =19.8 meters**
    - **Receiver noise** temperature: 200K
- AMT TX-RX link

    - **Free space path loss model (with pathloss exponent of 2) with TX-RX distance of 320 km (worst case)**
    - **AMT signal: 2373-2378 MHz with the center frequency of 2375.5 MHz (5 MHz AMT bandwidth**)
- MBAN transmitter

- **Omni-directional transmit antenna with 0 dBi antenna gain, height = 1.5 m**
- **1 mW transmission power, with different bandwidth options (2, 3, and 5 MHz)**
- **In** the 2 MHz channel spacing case, 2361-2399 MHz divides into 19 2 MHz channels (two 1 MHz guard bands used at both edges); in the 3 MHz channel spacing case, 2362-2398 MHz divides into 12 3 MHz channels (two 2 MHz guard bands at both edges); In the 5 MHz channel spacing case, 2362.5-2397.5 MHz divides into 7 5 MHz channels (two 2.5 MHz guard bands at both edges);

- MBAN-AMT-RX link

  - **Extended Hata pathloss model used (more realistic radio propagation model) with urban, suburban, and open space environment settings.**
  - **MBAN**-AMT-RX distance = 10 km
- 1000,000 simulations performed for each case.

The extended Hata pathloss model used is a realistic model to simulate MBAN propagation because it is a widely adopted model for mobile and other services working in non-LOS/cluttered environments with supported frequency range from 30 MHz to 3 GHz and TX-RX distance up to 100 km.

A total of 11 cases were studied to cover different MBAN/AMT co-existence scenarios.

- Case 0: No MBAN interference source, AMT link operating with a distance of 320km

In this case, there is no MBAN signal. The AMT transmitter and receiver are separated by a distance of 320 km and the AMT receiver has perfect tracking of the AMT transmitter, which means the AMT transmitter is always in the main-lobe of the AMT RX antenna. This case is to study the AMT link performance under realistic settings with no interference.

Figure 4 shows the AMT link signal-to-noise ratio (SNR) distribution when there is no interference signal. Due to the random nature of the AMT transmit antenna gain, the SNR at the AMT receiver is a random variable.

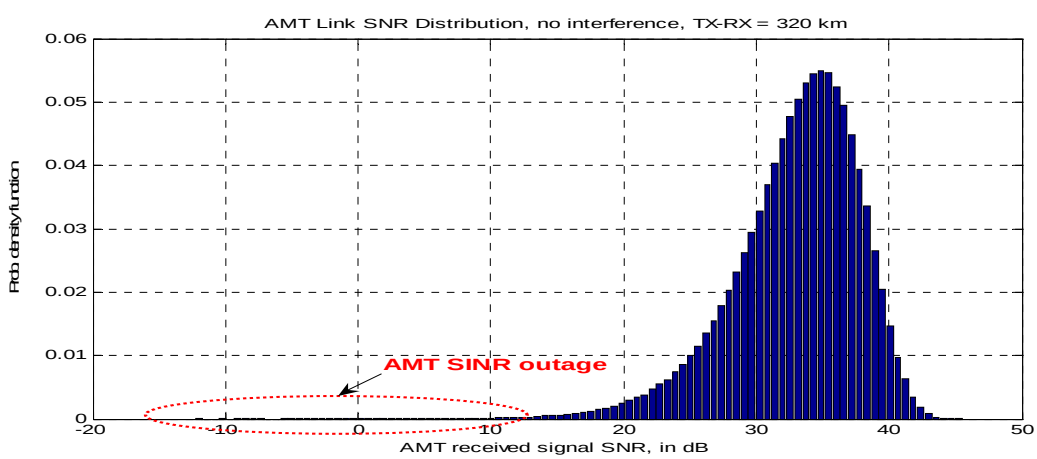

Figure 4 AMT received signal SNR distribution without MBAN interference

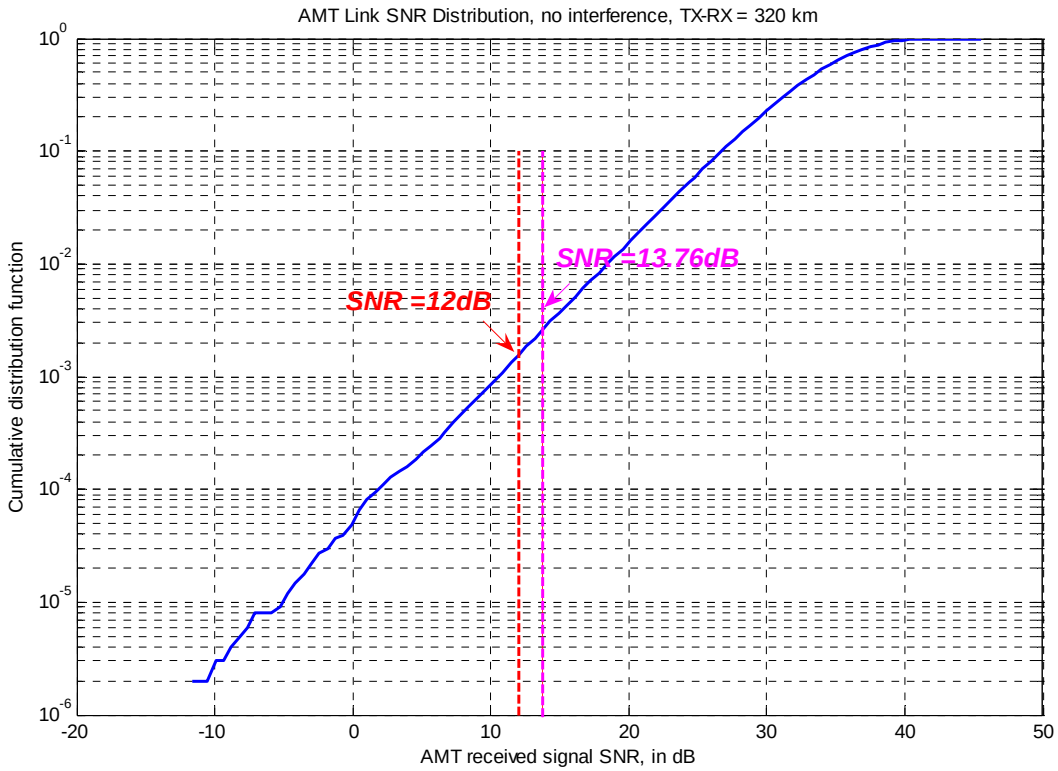

Figure 5 AMT received signal SNR cdf distribution without MBAN interference

Based on ITU-R M.1459, the minimum required C/N for AMT operations is 9 - 15 dB.

Hence, it is reasonable to assume that the minimum required signal-to-noise-plus-interference-ratio (SINR) to maintain AMT operations is 12 dB.

Figure 5 shows that the probability that an AMT link has a SINR (which is the same as SNR in this case since there is no interference) of less than 12 dB is as high as 0.0016 even when there is no interference present. In other words, with a probability of 0.0016, an AMT link is in SINR outage even when there is no interference. **"**SINR outage" is defined as the event that the instantaneous signal-to-interference-plus-noise-ratio of an AMT link is below the minimum required value for AMT operations.

It is worth noting that SINR outage does not necessarily mean that the AMT link between an AMT site and an aircraft is broken. Due to the high speeds of aircraft, the SINR at an AMT receiver changes very quickly and this makes time-domain diversity techniques, such as retransmission and coding over a long block, very effective in counteracting SINR outages. Other diversity schemes, such as spatial diversity, also can effectively mitigate the effect of SINR outage.

The above analysis demonstrates that current AMT systems tolerate some SINR outage during normal operations.

In ITU-R M.1459, it is also stated that "the maximum practical value of interference to noise ratio (I/N) is considered to be approximately 0.5 (-3 dB) with smaller value desirable". Therefore, interference with I/N = 0.5 would be acceptable to AMT systems. With I/N = 0.5, the requirement of SINR >= 12 dB is equivalent to SNR >= 13.76 dB:

$SINR = S/(I+N) = S/(0.5N+N) = (S/N) / 1.5 = (SNR)_{dB} - 10*\log_{10}(1.5) = 12$ dB

$(SNR)_{dB} = 12 + 10*\log_{10}(1.5) = 13.76$ dB

Thus, with an interference power 3 dB less than the noise power, the probability that an AMT link is in SINR outage (i.e., SINR < 12 dB or SNR < 13.76dB) is 0.0026. Therefore, it is reasonable to believe that AMT systems can tolerate no larger than 0.0026 SINR outage probability. We will use P(SINR < 12 dB) < 0.0026 as the design criteria to determine the exclusion zone radius. The radius of exclusion zones should be large enough to guarantee that with interference from MBAN, an AMT receiver can still achieve P(SINR < 12 dB) < 0.0026.

- Case 1: One MBAN network with 100% duty cycle, always in the main-lobe of the AMT RX antenna
    - **Both the elevation angle and the azimuth angle are zero (AMT TX, RX, and MBAN TX are always in line with each other, worst case)**
    - **AMT TX-RX distance = 320 km**
    - **MBAN-**AMT link
        - Suburban environment
        - Indoor-2-outdoor, with a random wall attenuation (mean = 10 dB, std = 5 dB)
        - In-band interference, the MBAN channel 2375-2377 MHz is used
        - MBAN-AMT-RX distance = 10 km

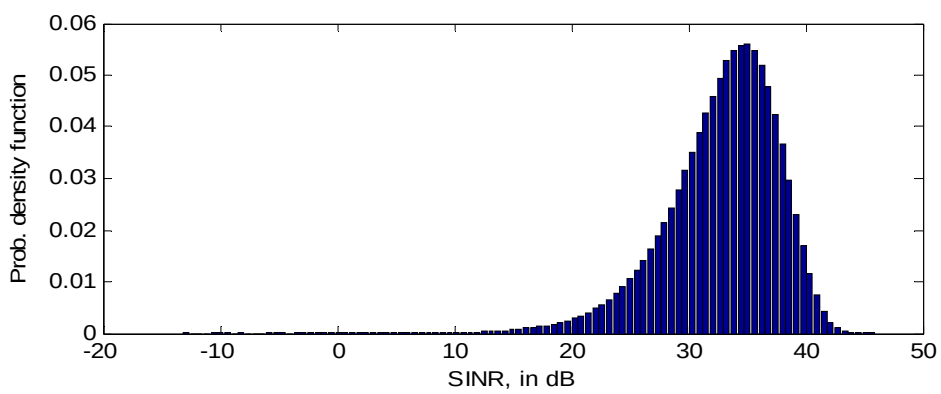

Figure 6 Case 1, AMT received signal SINR pdf distribution

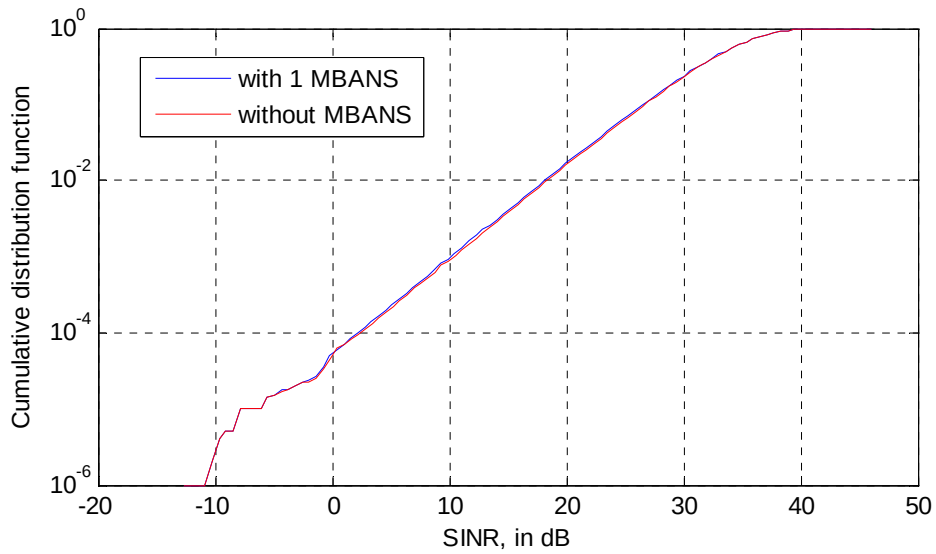

Figure 7 Case 1, 1, AMT received signal SINR cdf distribution

Simulation results shows that P(SINR < 12 dB) = 0.0017 < 0.0026. Compared with case 0, there is almost no increase of SINR outage probability, even when an MBAN network keeps transmitting within the AMT receiver main-beam in the AMT band. This is because the 10 km separation distance and the wall attenuation can significantly reduce the interference probability. Limiting MBAN operations in the 2360-2390 MHz band for in-door use only can greatly mitigate the MBAN interference to AMT. In this case, 10 km separation is sufficient to protect AMT receivers.

- Case 2: Multiple MBAN networks with random geographic relative locations to AMT receiver

    - **10 MBAN networks with 100% duty cycle, each with a random relative position to the AMT receiver main beam.**
    - **MBAN interference link has an elevation angle of 0.984^0 (aircraft at 320 km distance and 5520 m height)**
    - **MBAN interference link has a random azimuth angle with a uniform distribution in [0, 360^0]**
    - **AMT TX-RX distance = 320 km**
    - **MBAN-AMT link:**
    - **Suburban environment**
    - **Outdoor-2-outdoor, no wall attenuation**
    - **In-band interference, the MBAN channel 2375-2377 MHz is used**
    - **MBAN-AMT-RX distance** = 10 km

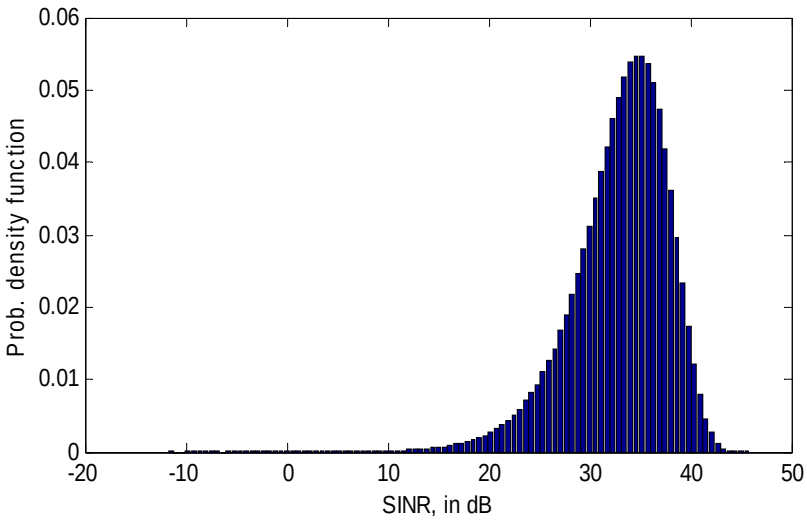

Figure 8 Case 2, AMT received signal SINR pdf distribution

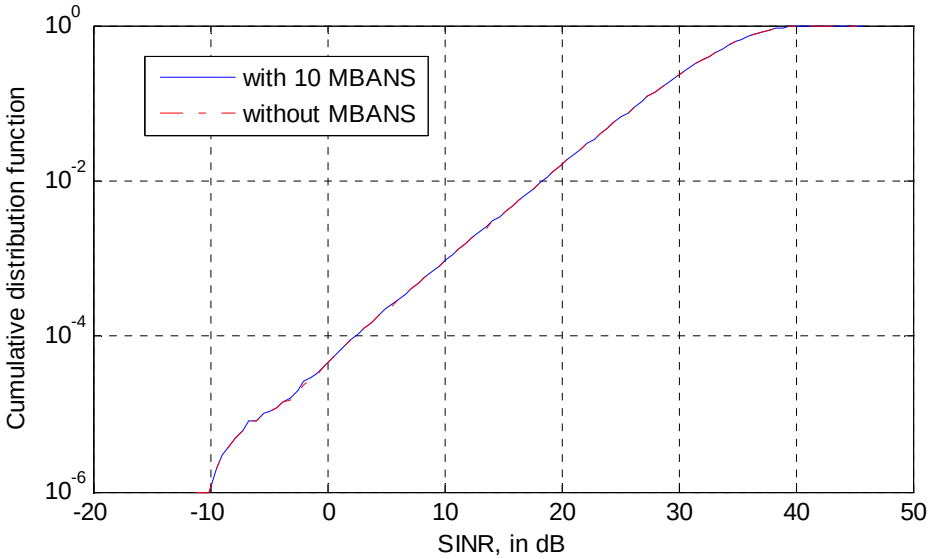

Figure 9 Case 2, AMT received signal SINR cdf distribution

Simulation results shows that P(SINR < 12dB) = 0.0016 < 0.0026. Compared with case 0, there is almost no increase of SINR outage probability, even when 10 MBAN networks keep transmitting within the AMT band and there is no wall attenuation included. **This is because the random geographic locations of the MBAN networks relative to the AMT receiver and the highly directional antenna used by the AMT receiver significantly reduces the interference probability.** In this case, a 10 km separation is sufficient to protect AMT receivers.

- Case 3: 50 MBAN networks with 100% duty cycle, each with a random relative position to the AMT receiver, with randomly selected MBAN channels

    - **MBAN interference link has an elevation angle of 0.984^0 (aircraft at 320 km distance and 5520m height)**
    - **MBAN interference link has a random azimuth angle with a uniform distribution in [0, 360^0]**
    - **AMT TX-RX distance = 320 km**
    - **MBAN-**AMT link
        - Suburban environment
        - Outdoor-2-outdoor, **no wall attenuation**
        - MBAN channels are randomly chosen from all 19 channels (2360-2361 MHz and 2399-2400 MHz are used as guard bands) , with 2 MHz channel bandwidth
        - MBAN-AMT-RX distance = 10 km

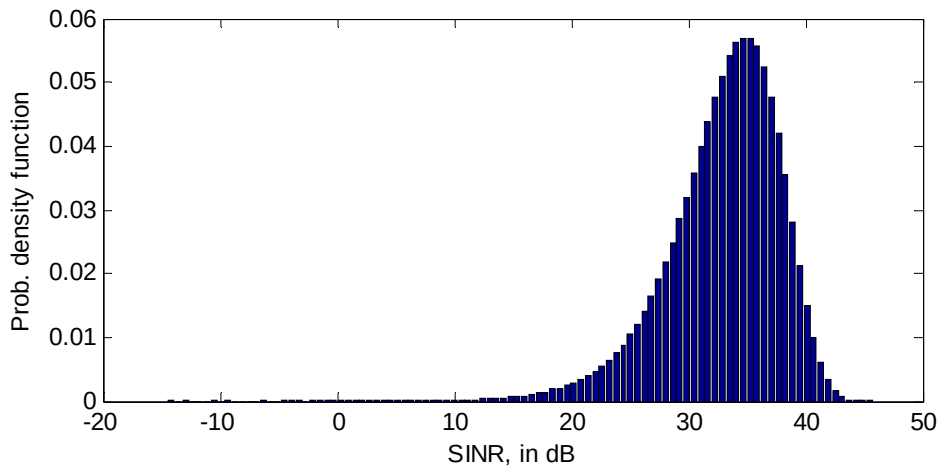

Figure 10 Case 3, AMT received signal SINR pdf distribution

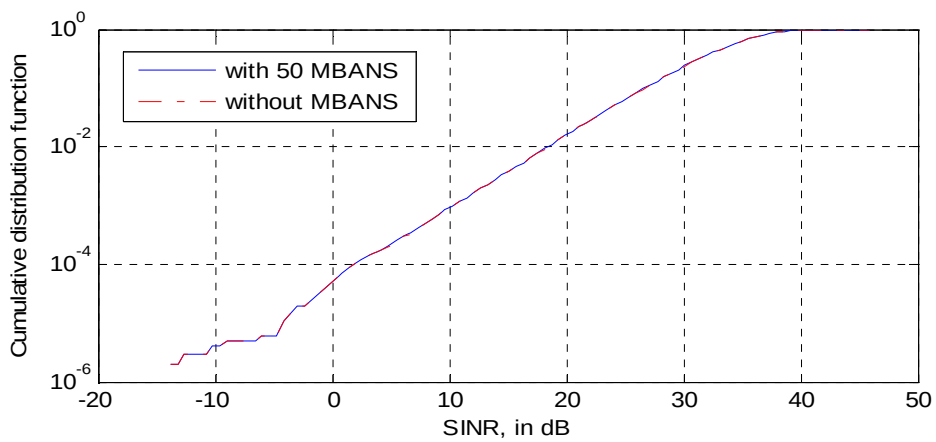

Figure 11 Case 3, AMT received signal SINR cdf distribution

Simulation results shows that P(SINR < 12dB) = 0.0016 < 0.0026. Compared with case 0, there is almost no increase of SINR outage probability, even when 50 MBAN networks keep transmitting within the AMT band and there is no wall attenuation included. This is because the random geographic locations of MBAN networks relative to the AMT receiver and the highly directional antenna used by the AMT receiver significantly reduces the interference probability. Moreover, the large amount of spectrum (40 MHz) provides abundant channels for MBAN to select from and therefore significantly reduces the probability that an MBAN network operates within the AMT channel. In this case, 10 km separation is sufficient to protect AMT receivers.

- Case 4: Realistic case – One large hospital in a urban area located in the main-lobe of an AMT receiver antenna
    - 800 MBAN networks with 25% duty cycle, always in the main-lobe of the AMT RX antenna
        - **MBAN interference link has an elevation angle of 0.984^0 (aircraft at 320 km distance and 5520m height)**
        - **MBAN interference link has a random azimuth angle with a uniform distribution in $[-1^{0,}\ 1^0]$** (in the main-lobe)
    - AMT TX-RX distance = 320 km
    - MBAN-AMT link
        - **Urban environment**
        - **Indoor-2-outdoor, with a random wall attenuation (mean = 10 dB, std = 5 dB)**
        - **MBAN channels are randomly chosen from all 19 channels (2360-2361 MHz and 2399-2400 MHz are used as guard bands) with 2 MHz channel bandwidth**
        - **MBAN**-AMT-RX distance = 10 km
    - Simulate a more realistic hospital case
        - 800 beds, each has 25% duty cycle (conservative estimation), indoor, in an urban area

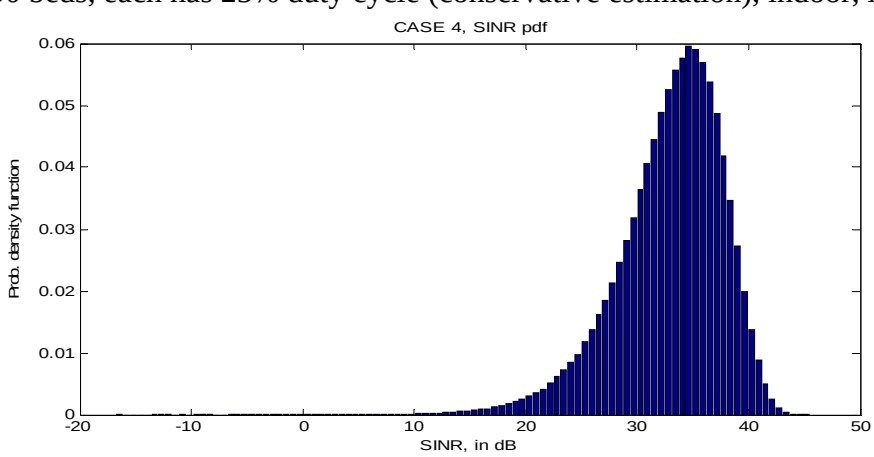

Figure 12 Case 4, AMT received signal SINR pdf distribution

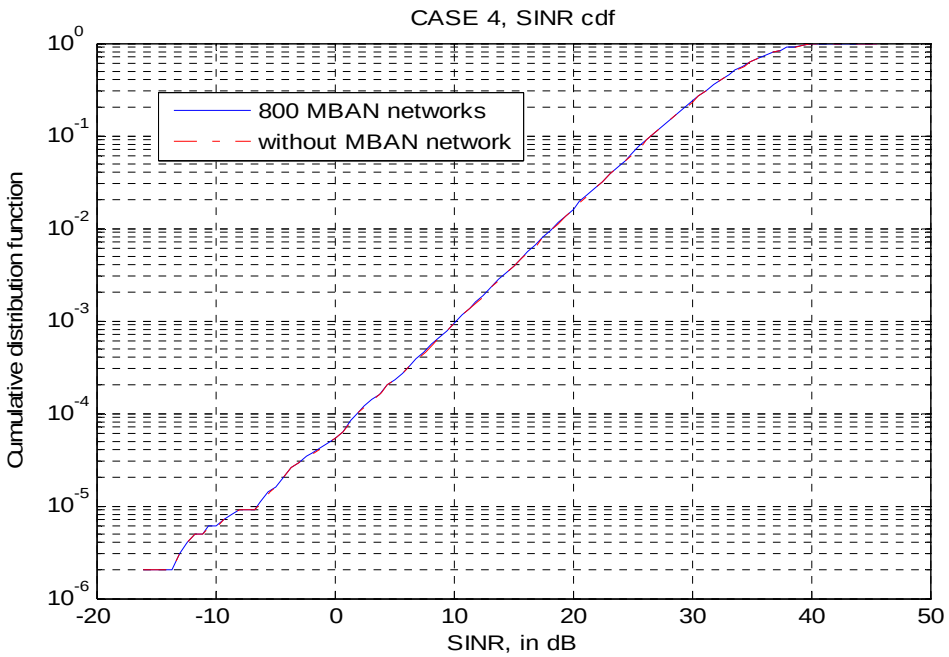

Figure 13 Case 4, AMT received signal SINR cdf distribution

Simulation results show that P(SINR < 12dB) = 0.0016 < 0.0026 with the exclusion zone radius of 10km. Compared with case 0, there is almost no increase of SINR outage probability, even when 800 MBAN networks operate within the AMT band. **This is because of the large amount of spectrum (40 MHz), low duty-cycle operations, relatively higher pathloss in an urban environment, and wall attenuation.** In this case, 10 km separation is sufficient to protect AMT receivers.

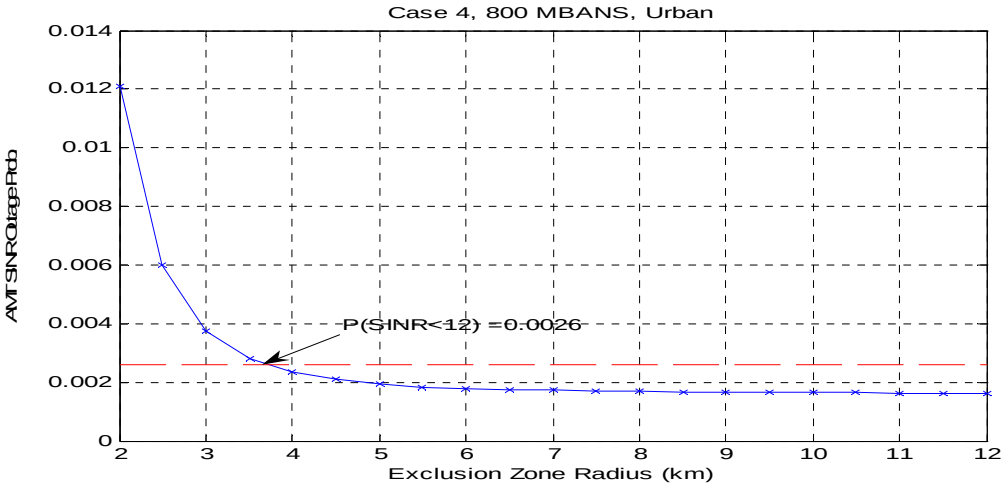

Figure 14 Case 4, AMT SINR Outage Probability

The above figure shows the AMT SINR outage probability as a function of the exclusion zone radius. An exclusion zone radius that is larger than 3.8 km can achieve a SINR outage probability less than 0.0026. An 11.5km exclusion zone radius is therefore sufficient in this case.

- Case 5: Realistic case – One large hospital in a suburban area located in the main-lobe of an AMT receiver antenna

  - 800 MBAN networks with 25% duty cycle, **always** in the main-lobe of the AMT RX antenna

    - **MBAN interference link has an elevation angle of 0.984^0 (aircraft at 320 km distance and 5520m height)**
    - **MBAN interference link has a random azimuth angle with a uniform distribution in [$-1^{0,}$ 1^0] (in** the main-lobe)
  - AMT TX-RX distance = 320 km
  - MBAN-AMT link

    - **Suburban environment**
    - **Indoor-2-outdoor, with a random wall attenuation (mean = 10 dB, std = 5 dB)**
    - **MBAN channels are randomly chosen from all 19 channels (2360-2361 MHz and 2399-2400 MHz are used as guard bands) , with 2 MHz channel bandwidth**
    - **MBAN**-AMT-RX distance = 10 km
  - Simulate a more realistic hospital case

    - 800 beds, each has 25% duty cycle (conservative estimation), indoor, in an suburban area

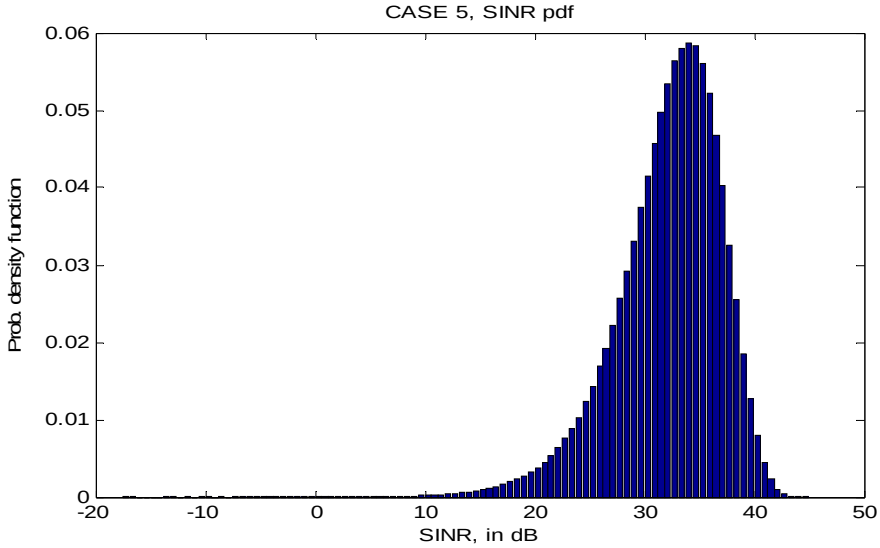

Figure 15 Case 5, AMT received signal SINR pdf distribution

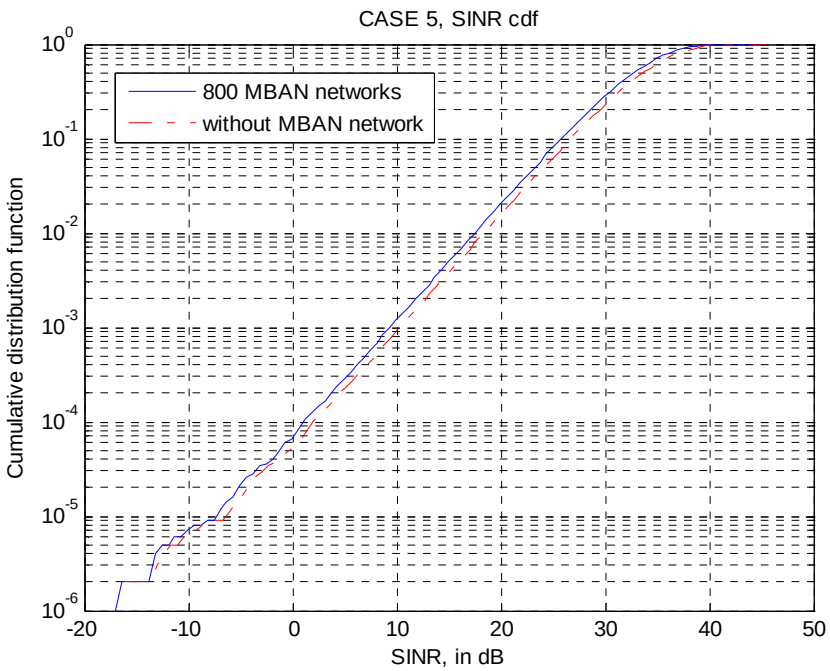

Figure 16 Case 5, AMT received signal SINR cdf distribution

Simulation results shows that P(SINR < 12dB) = 0.0021 < 0.0026 with the exclusion zone radius of 10 km. Compared with case 0, the increase of SINR outage probability introduced by 800 MBAN networks is negligible.

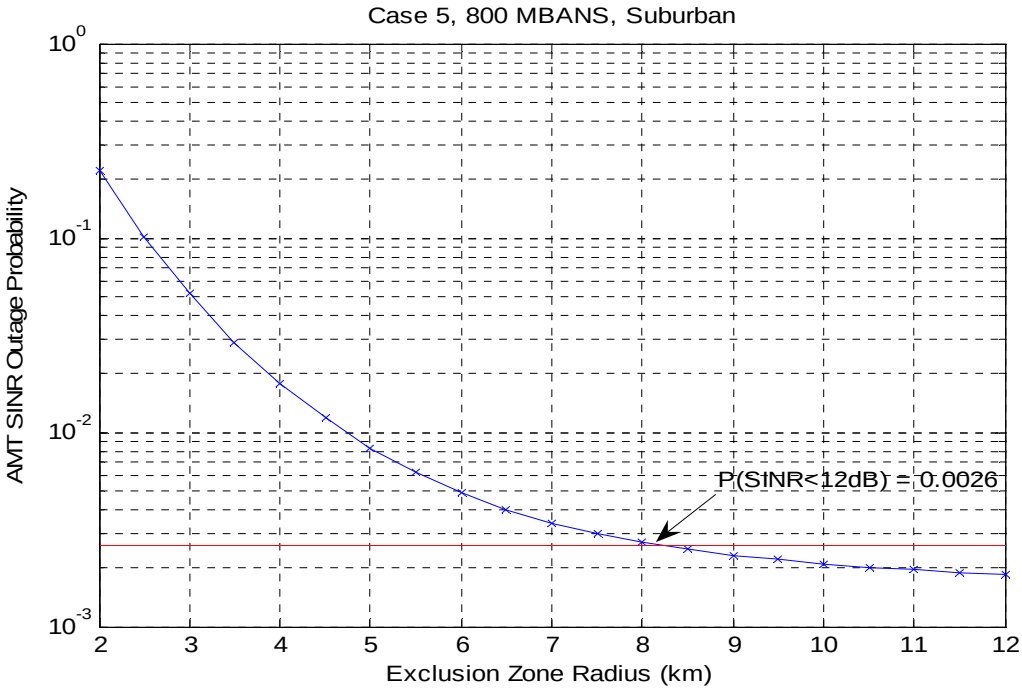

Figure 17 Case 5, AMT SINR Outage Probability

The above figure shows that an exclusion zone radius that is larger than 8.3 km can achieve a SINR outage probability less than 0.0026. Thus, a 11.5 km exclusion zone radius is sufficient in this case.

- Case 6: Repeat Case 4, but with MBAN channel bandwidth of 3 MHz
  - 800 MBAN networks with 25% duty cycle, **always** in the main-lobe of the AMT RX antenna
    - **MBAN interference link has an elevation angle of 0.984^0 (aircraft at 320 km distance and 5520m height)**
    - **MBAN interference link has a random azimuth angle with a uniform distribution in $[-1^0, 1^0]$** (in the main-lobe)
  - AMT TX-RX distance = 320 km
  - MBAN-AMT link
    - **Urban environment**
    - **Indoor-2-outdoor, with a random wall attenuation (mean = 10 dB, std = 5 dB)**
    - **MBAN** channels are randomly chosen from all 12 channels (2360-2362 MHz and 2398-2400 MHz are used as guard bands), with 3 MHz channel bandwidth.
  - Simulate a more realistic hospital case
    - 800 beds, each has 25% duty cycle (conservative estimation), indoor, in an urban area

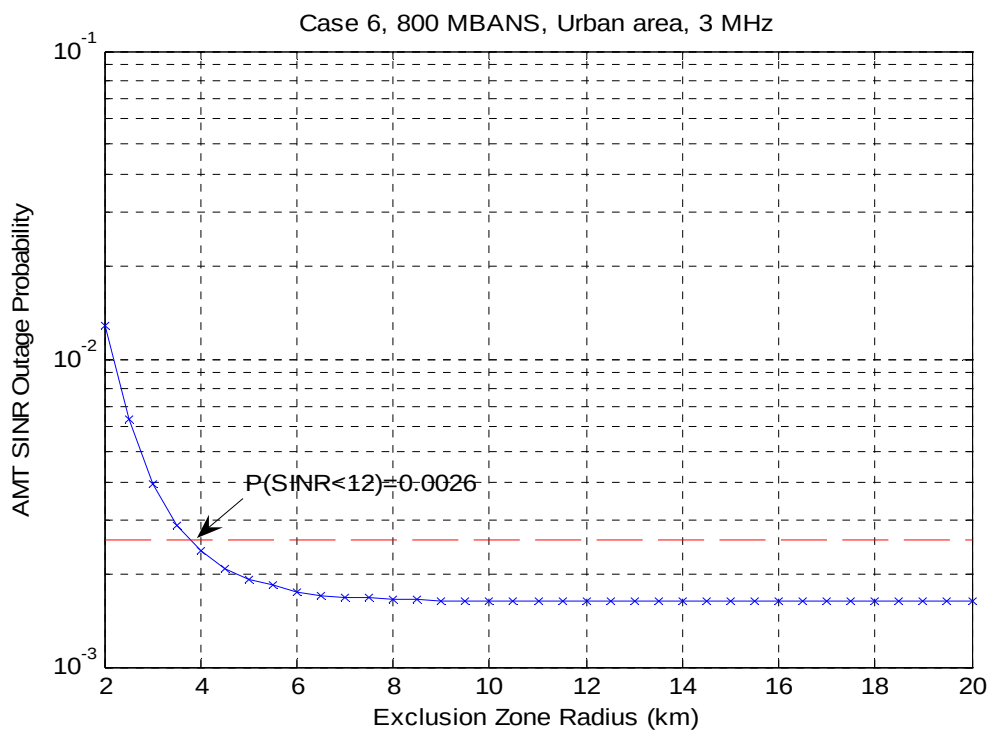

Figure 18 Case 6, AMT SINR Outage Probability

The above figure shows that an exclusion zone radius that is larger than 3.8 km can achieve a SINR outage probability of less than 0.0026. An 11.5 km exclusion zone radius is thus sufficient in this case. Also, it is worth noting that increasing the channel bandwidth & spacing from 2 MHz to 3 MHz does not change the AMT SINR outage probability distribution.

- Case 7: Repeat Case 5, but with MBAN channel bandwidth of 3 MHz
    - 800 MBAN networks with 25% duty cycle, **always** in the main-lobe of the AMT RX antenna
        - **MBAN interference link has an elevation angle of 0.984^0 (aircraft at 320 km distance and 5520m height)**
        - **MBAN interference link has a random azimuth angle with a uniform distribution in $[-1^0, 1^0]$** (in the main-lobe)
    - AMT TX-RX distance = 320 km
    - MBAN-AMT link
        - **Suburban environment**
        - **Indoor-2-outdoor, with a random wall attenuation (mean = 10 dB, std = 5 dB)**
        - **MBAN channels are randomly chosen from all 12 channels (2360-2362 MHz and 2398-2400** MHz are used as guard bands) , with 3 MHz channel bandwidth.
    - Simulate a more realistic hospital case
        - 800 beds, each has 25% duty cycle (conservative estimation), indoor, in a suburban area.

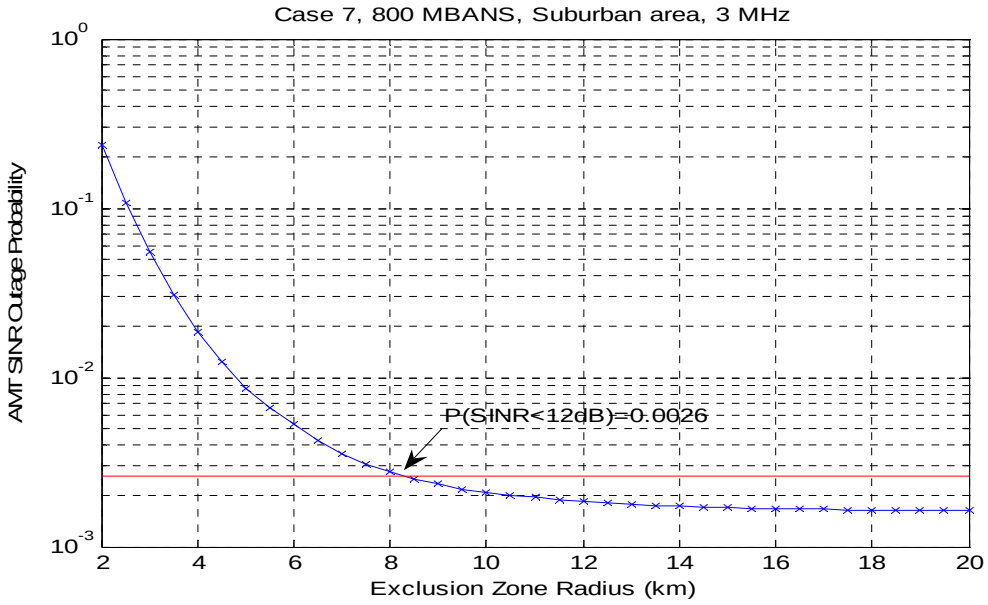

Figure 19 Case 7, AMT SINR Outage Probability

The above figure shows that an exclusion zone radius that is larger than 8.3 km can achieve a SINR outage probability of less than 0.0026. The 11.5 km exclusion zone radius is thus sufficient

in this case. Again, increasing the channel bandwidth & spacing from 2 MHz to 3 MHz does not change the AMT SINR outage probability distribution.

- Case 8: Repeat Case 4, but with MBAN channel bandwidth of 5 MHz
  - 800 MBAN networks with 25% duty cycle, **always** in the main-lobe of the AMT RX antenna
    - **MBAN interference link has an elevation angle of 0.984^0 (aircraft at 320 km distance and 5520m height)**
    - **MBAN** interference link has a random azimuth angle with a uniform distribution in [-$1^{0,}$ 1^0] (in the main-lobe)
  - AMT TX-RX distance = 320 km
  - MBAN-AMT link
    - **urban environment**
    - **Indoor-2-outdoor, with a random wall attenuation (mean = 10 dB, std = 5 dB)**
    - **MBAN** channels are randomly chosen from all 7 channels (2360-2362.5 and 2397.5-2400 MHz are used as guard bands) , with 5 MHz channel bandwidth
  - Simulate a more realistic hospital case
    - 800 beds, each has 25% duty cycle (conservative estimation), indoor, in an urban area.

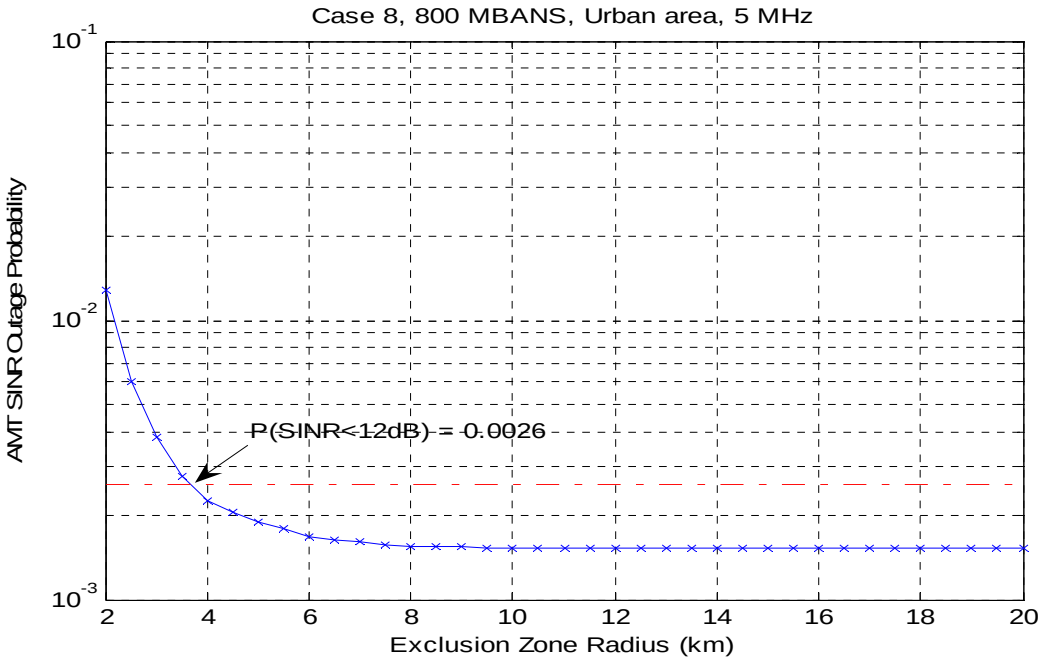

Figure 20 Case 8, AMT SINR Outage Probability

The above figure shows that an exclusion zone radius that is larger than 3.8 km can achieve a SINR outage probability less than 0.0026. A 11.5 km exclusion zone radius is thus sufficient in

this case. It is worth noting that there is no obvious change of the AMT SINR outage probability distribution caused by increasing the channel bandwidth & spacing from 2 MHz to 5 MHz.

- Case 9: Repeat Case 5, but with MBAN channel bandwidth of 5 MHz
    - 800 MBAN networks with 25% duty cycle, **always** in the main-lobe of the AMT RX antenna
        - **MBAN interference link has an elevation angle of 0.984^0 (aircraft at 320 km distance and 5520m height)**
        - **MBAN interference link has a random azimuth angle with a uniform distribution in $[-1^0, 1^0]$** (in the main-lobe)
    - AMT TX-RX distance = 320 km
    - MBAN-AMT link
        - **Suburban environment**
        - **Indoor-2-outdoor, with a random wall attenuation (mean = 10 dB, std = 5 dB)**
        - **MBAN** channels are randomly chosen from all 7 channels (2360-2362.5 and 2397.5-2400 MHz are used as guard bands) , with 5 MHz channel bandwidth
    - Simulate a more realistic hospital case
        - 800 beds, each has 25% duty cycle (conservative estimation), indoor, in a suburban area.

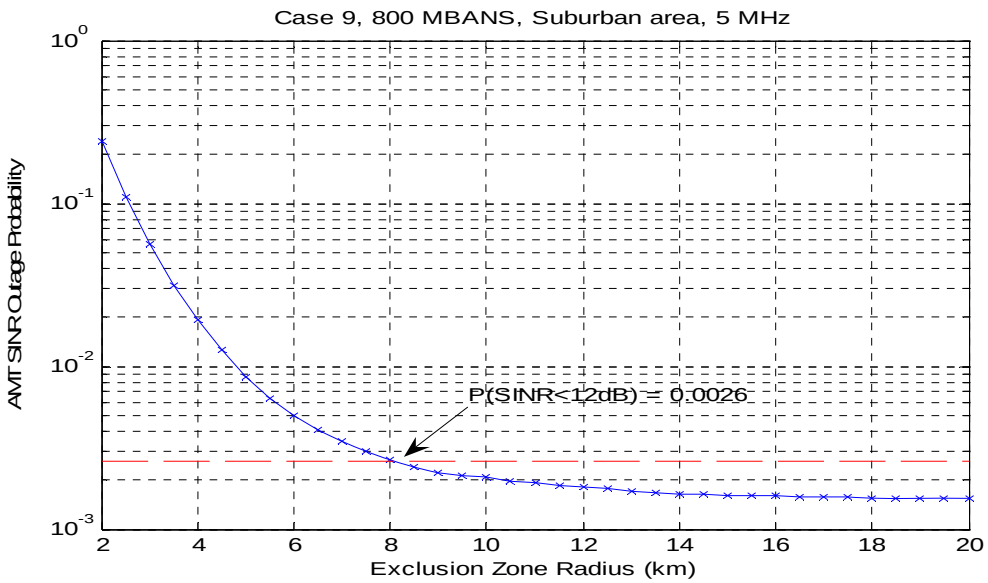

Figure 21 Case 9, AMT SINR Outage Probability

The above figure shows that an exclusion zone radius that is larger than 8.1 km can achieve a SINR outage probability less than 0.0026. An 11.5 km exclusion zone radius is thus sufficient in

this case. Again, increasing the channel bandwidth & spacing from 2 MHz to 5 MHz does not change the AMT SINR outage probability distribution.

- Case 10: Realistic case- Small hospital in a rural area
  - 20 MBAN network with 25% duty cycle, **always** in the main-lobe of the AMT RX antenna
    - **MBAN interference link has an elevation angle of 0.984^0 (aircraft at 320 km distance and 5520m height)**
    - **MBAN** interference link has a random azimuth angle with a uniform distribution in [-$1^{0,}$ 1^0] (in the main-lobe)
  - AMT TX-RX distance = 320 km
  - MBAN-AMT link
    - **Rural environment (the open area option in the extended Hata model adopted)**
    - **Indoor-2-outdoor, with a random wall attenuation (mean = 10 dB, std = 5 dB)**
    - **MBAN** channels are randomly chosen from all 12 channels (2360-2362 and 2398-2400 MHz are used as guard bands) , 3 MHz channel bandwidth.
  - Simulate a more realistic hospital case
    - 20 beds, each has 25% duty cycle (conservative estimation), indoor, in a rural area.

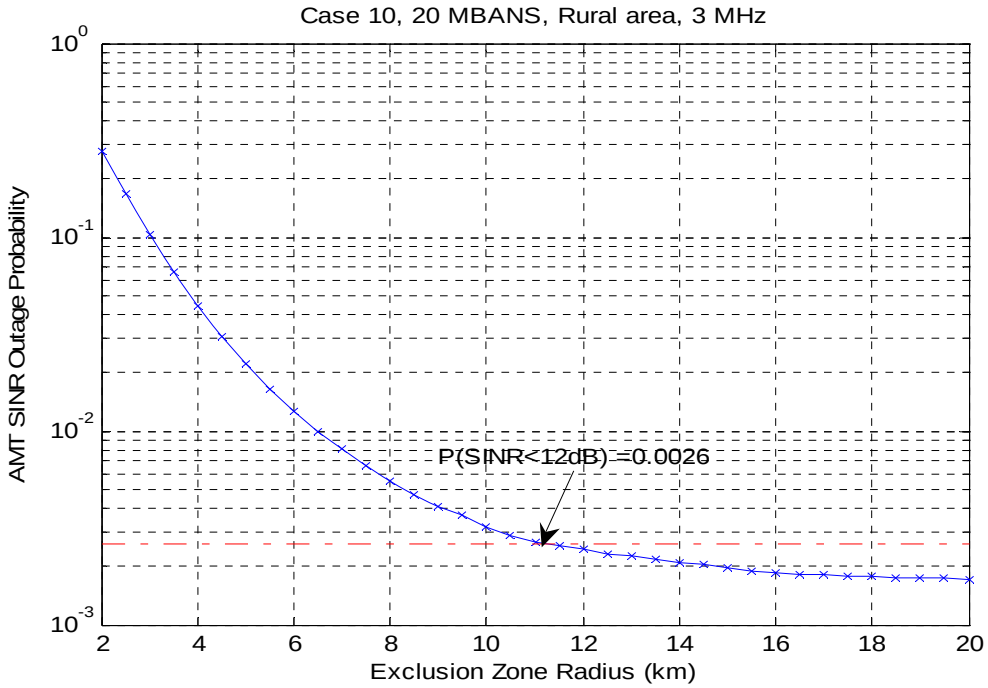

Figure 22 Case 10, AMT SINR Outage Probability

In this case, 11.5 km exclusion zone radius is sufficient to guarantee that the AMT SINR outage probability is lower than 0.0026.

- Case 11: Repeat Case 10, but with MBAN channel bandwidth of 5 MHz
  - 20 MBAN networks with 25% duty cycle, **always** in the main-lobe of the AMT RX antenna
    - **MBAN interference link has an elevation angle of 0.984^0 (aircraft at 320 km distance and 5520m height)**
    - **MBAN** interference link has a random azimuth angle with a uniform distribution in [-1^{0,} 1^0] (in the main-lobe)
  - AMT TX-RX distance = 320 km
  - MBAN-AMT link
    - **Rural environment (the open area option in the extended Hata model adopted)**
    - **Indoor-2-outdoor, with a random wall attenuation (mean = 10 dB, std = 5 dB)**
    - **MBAN** channels are randomly chosen from all 7 channels (2360-2362.5 and 2397.5-2400 MHz are used as guard bands), with 5 MHz channel bandwidth.
  - Simulate a more realistic hospital case
    - 20 beds, each has 25% duty cycle (conservative estimation), indoor, in a rural area.

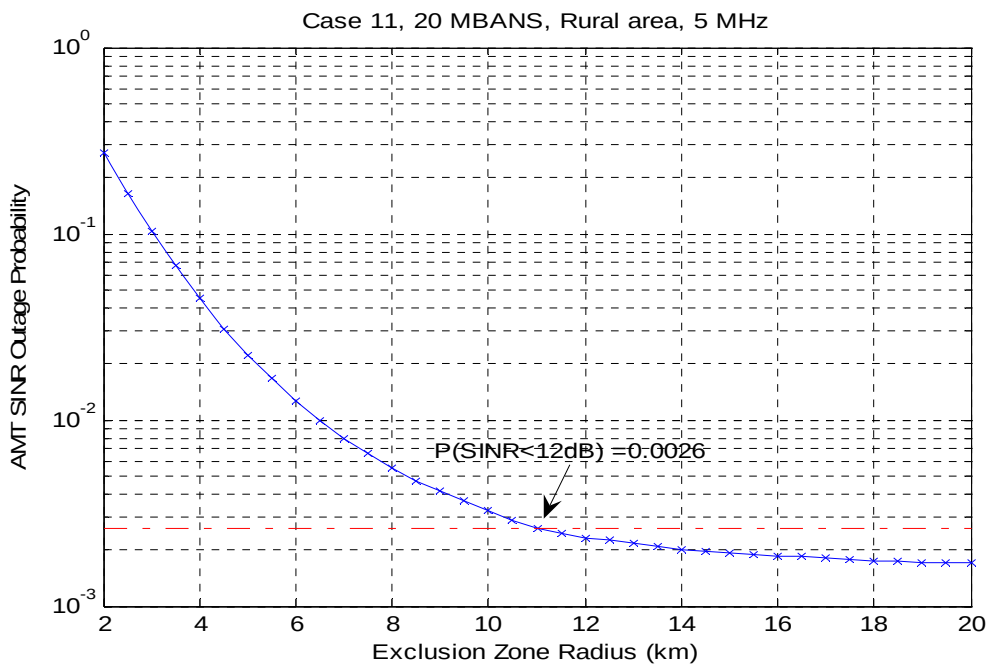

Figure 23 Case 11, AMT SINR Outage Probability

In this case, 11.5 km exclusion zone radius is sufficient to guarantee that the AMT SINR outage probability is lower than 0.0026.

It is worth to emphasize our results are obtained based on the following conservative assumptions.

- AMT TX-RX distance fixed to 320km (which is the worst case)
- All MBAN devices always within the AMT antenna main lobe (which is quite conservative)
- All MBAN networks operating with 25% duty cycle (which means fully-loaded networks and is the worst case)
- All MBAN networks operating with the maximum allowed transmit power (which is the worst case, while in reality dynamic power control would enable MBAN devices to operate with lower transmission power)
- Possible human body blockage loss not included in the calculation of MBAN interference power.
- A highest AMT receiver antenna gain, 41.2dBi, assumed, which is not commonly used in current AMT systems. A typical AMT receiver antenna has a small size and lower antenna gain (e.g. 31dBi). A higher AMT receiver antenna gain usually means a larger exclusion zone radius.

Therefore, the above exclusion zone radius results should be considered as conservative estimations. In fact, an exclusion zone radius of 9.7km, which has been proposed by GEHC would be enough to protect AMT sites in most cases.

In summary, our results match previous results from GEHC for 1 MHz channel bandwidth systems quite well and demonstrate that a 11.5 km exclusion zone radius is more than adequate to protect AMT operations, irrespective of the bandwidth of the MBAN devices (1, 2, 3 or 5 MHZ) and operating scenario (urban, suburban and rural)The simulations also demonstrate that a wider spectrum allocation is important in terms of supporting AMT/MBAN coexistence with minimal interference.

4. MAXIMUM TRANSMITTER POWER

We propose the following transmitter power limits to meet the requirements of both in-hospital and in-home MBAN applications.

- For the 2360- 390 MHz band: 1 mW/MHz with the total power <= 1 mW.
- For the 2390-2400 MHz band: 20mW (or 13dBm).

The proposed transmitted power limits enables medical body area networks to achieve medical-grade reliability with currently-available commercial technologies while minimizing the potential for interference to other co-channel users.

A link budget analysis is presented to demonstrate that the proposed 1 mW (for bandwidth > 1 MHz cases) and 1mW/MHz (for bandwidth <= 1MHz cases) is sufficient to meet the performance requirements of typical short-range MBAN applications. For MBAN applications with all levels of acuity, an application-level bit error rate (BER) no larger than 10^{-6} is acceptable to guarantee quality-of-service. Considering possible retransmission techniques that could be adopted to improve application-level BER performance, we assume the minimum physical layer bit error rate (BER) is 10^{-4} in our analysis. This assumption is reasonable and with such physical-layer BER performance requirement and retransmission techniques, it is feasible to achieve the required quality-of-service of MBAN applications. The BER performance curves of several

popular 2.4 GHz short-range radio solutions, including 802.15.4 DSSS + O-QPSK with a 20 dB bandwidth of 2.6 MHz, O-QPSK with a 20 dB BW of 2.6 MHz and FSK modulation with 1 MHz bandwidth, are shown in Fig 25. The simulated channel mode is the additive white Gaussian noise (AWGN) channel.

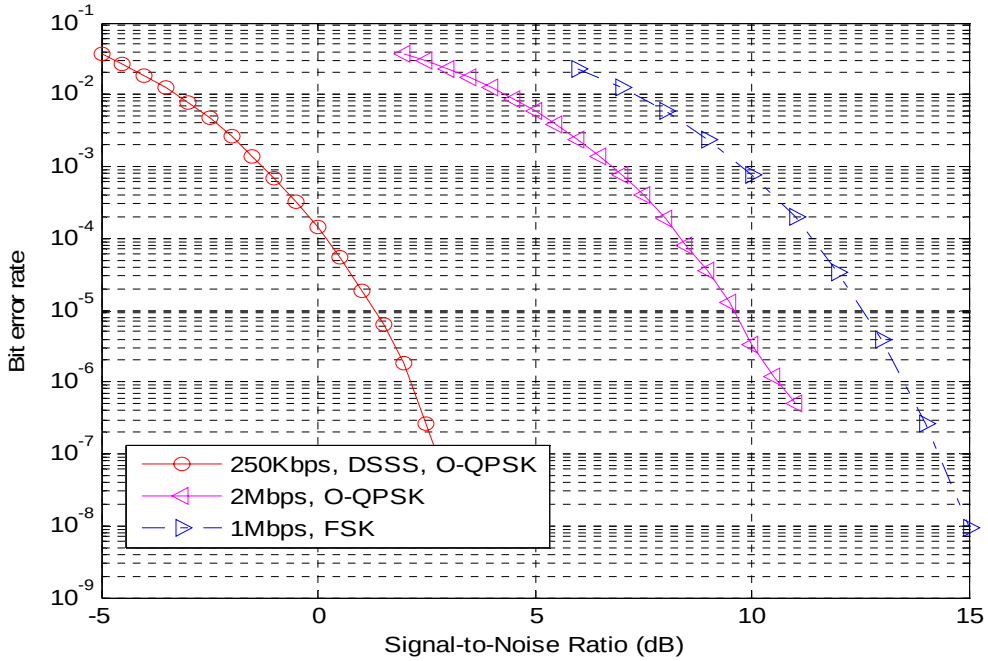

Figure 24 BER performance of several mature modulation schemes

For communications between an on-body device (e.g. sensors) to an external device (e.g. bedside patient monitoring unit), the assumptions used in the analysis are: AWGN channel model, 3 meter communication range, 0 dBi TX and RX antennas, free-space path loss, central frequency of 2400 MHz (worst case), 10 dB noise figure and 6 dB implementation loss. Table 1 summarizes the link budget analysis results.

Parameter	DSSS O-QPSK	O-QPSK	FSK
Information data rate (R_b) [Mbps]	0.25	2	1
Average TX power (P_T)[dBm]	0	0	0
TX antenna gain (G_T)[dBi]	0	0	0
Center frequency (f_c) [MHz]	2400	2400	2400
Path loss at 3 meter, $L_1 = 20\log_{10}\{(4\pi f_c d/(3\times 10^8))\}[dB]$	49.6	49.6	49.6
RX antenna gain (G_R) [dBi]	0	0	0
RX power ($P_R = P_T + G_T + G_R - L_1$) at $3m$	-49.6	-49.6	-49.6
Average noise power ($N = -174 + 10 * log_{10}(BW)$) [dBm]	-111	-111	-114
RX noise figure referred to the antenna terminal (N_F) [dB]	10	10	10
Total noise power ($P_N = N + N_F$) [dBm]	-101	-101	-104
Required Minimum SNR (S) [dB]	0.18	8.37	11.38
Implementation loss (I) [dB]	6	6	6
Link Margin ($M = P_R - P_N - S - I$), $d = 3$m [dB]	45.22	37.03	37.02

Table 1 Link Budget Analysis for MBAN links between on-body sensors to external hub devices

Link margins as high as 37dB are achieved in both FSK (1 Mbps, 1 MHz BW) and O-QPSK (2 Mbps, 2.6 MHz BW) cases. In the DSSS O-QPSK case (IEEE 802.15.4 PHY solution), the achieved link margin is even higher, 45.22 dB. These high link margins can be used to counteract the fading effects introduced by the presence of the human body and imperfect antenna orientation. For example, the channel fading statistics of 2360 - 2400 MHz band were calculated in [6] using the CM4 (on-body to external device) channel models developed by IEEE 802.15.6. It was shown that the 99%-tile fade depth at 3 meters is 19 dB. The link budgets after considering this 99% fade depth are summarized in Table 2.

Parameter	DSSS, O-QPSK	O-QPSK	FSK
AWGN link margin	45.22 dB	37.03 dB	37.02 dB
99% fade depth at 3 m, CM4	19 dB	19 dB	19 dB
Realistic Link Margin	26.22 dB	18.03 dB	18.02 dB

Table 2 Realistic link margins of MBAN links between on-body sensors to external hub devices

After considering the 19 dB 99%-tile fade, the achieved link margins with 0 dBm transmission power are 26.22 dB for the 802.15.4 solution, and 18 dB for the O-QPSK and FSK cases. The high link margins enable MBAN radios to tolerate moderate interference. For example, an 18 dB link margin can enable MBAN radios to tolerate an in-band interference signal (assume AWGN-like interference) with a power 18 dB higher than in-band noise power (i.e. -88.2dBm interference power). [The calculation is as follows: (I+N)/N = 10^(18/10) = 63.0957 => I = 62.0957 N = 17.93 dB + (N) dB].

Moreover, high link margins imply that the proposed 0 dBm transmission power limit is sufficient to support possibly higher data rate services in future MBAN applications which would require higher SNR.

For on-body communications (e.g. communications between a sensor device and an on-body hub device), realistic on-body channel models are used to do the link margin analysis. Here, we adopt the two CM3 (on-body) channel models for 2.4 GHz proposed in [5], which were developed in IEEE 802.15.6 based on extensive measurements conducted by different organizations

The first model was proposed by NICT (Japan) and the pathloss can be calculated as:

$$PL(d)[dB] = a * \log_{10}(d) + b + N$$

where a = 6.6 dB , b = 36.1 dB, N is a normally distributed variable with zero mean and standard deviation of 3.80 dB and d is the TX-RX distance in mm.

The second model was proposed by IMEC (Netherlands) and the pathloss formula is:

$$PL(d)[dB] = -10 * \log_{10}(P_0 e^{-m_0 d} + P_1) + N$$

where P_0 = -25.8 dB, m_0 = 2.0 dB/cm, P_1 = -71.3 dB, N is a normally distributed variable with zero mean and standard deviation of 3.80 dB and d is the TX-RX distance in cm.

With a TX-RX distance of 1 meter, the pathloss (in dB) generated with the NICT model is a normally distributed random variable with mean of 55.9 dB and standard deviation of 3.8 dB (i.e., with 99% probability an on-body channel with a TX-RX distance of 1 meter has a pathloss value lower than 55.9 + 2.3*3.8 = 64.64 dB) while the pathloss (in dB) generated with the IMEC model is a normally distributed random variable with mean of 71.27 dB and standard deviation of 3.6 dB (that i.e., with 99% probability an on-body channel with a TX-RX distance of 1 meter has a pathloss value lower than 71.27 + 2.3*3.6 = 79.55 dB). In our analysis, 79.55 dB is used as pathloss. It is worth noting that 79.55 dB is a conservative choice that covers most of the channel measurement results in the literature, for example see [7].

Parameter	DSSS O-QPSK	O-QPSK	FSK
Information data rate (R_b) [Mbps]	0.25	2	1
Average TX power (P_T)[dBm]	0	0	0
TX antenna gain (G_T)[dBi]	0	0	0
Center frequency (f_c) [MHz]	2400	2400	2400
Path loss with $TX - RX = 1$ meter [dB]	79.55	79.55	79.55
RX antenna gain (G_R) [dBi]	0	0	0
RX power ($P_R = P_T + G_T + G_R - L_1$) at $1m$	-79.55	-79.55	-79.55
Average noise power ($N = -174 + 10 * log_{10}(BW)$) [dBm]	-111	-111	-114
RX noise figure referred to the antenna terminal (N_F) [dB]	10	10	10
Total noise power ($P_N = N + N_F$) [dBm]	-101	-101	-104
Required Minimum SNR (S) [dB]	0.18	8.37	11.38
Implementation loss (I) [dB]	6	6	6
Link Margin ($M = P_R - P_N - S - I$), $d = 3$m [dB]	15.27	7.08	7.07

Table 3 Link Budget Analysis for on-body MBAN communications

Table 3 above shows that a 0 dBm transmission power can provide a 15.27 dB link margin in the DSSS O-QPSK case, 7.08 dB margin for O-QPSK, and 7.07 dB margin for FSK cases for on-body MBAN communications.

Based on the above analysis, we believe that 0 dBm transmission power limit is sufficient to provide medical-grade link performance for short-range MBAN applications. This is also confirmed by the receiver sensitivity parameters of commercially available 2.4 GHz transceivers from different vendors. With a 0 dBm transmission power and a pathloss of 79.55 dB (the higher of CM3 and CM4 channels), the receiver sensitivity of a MBAN transceiver must be -79.55 dBm or better. Below we list the sensitivity parameters of some commercial 2.4 GHz transceivers. It shows that most of commercially available 2.4GHz transceivers can achieve receiver sensitivity better than -79.55 dBm.

Transceiver chipsets	Technical Parameters	Receiver sensitivity
Texas Instruments/Chipcon CC2400	1 Mbps, 1 MHz channel BW, FSK 250 kbps, 1 MHz channel BW, FSK 10 kbps, 500 kHz channel BW, FSK	-87dBm @ BER =10^{-3} (or -85dBm @ BER = 10^{-4}) -91dBm @ BER =10^{-3} (or -89dBm @ BER = 10^{-4}) -101dBm @ BER =10^{-3} (or -99dBm @ BER = 10^{-4}) Note: a 2dB offset is added to get the sensitivity @ BER =10^{-4}.
Texas Instruments/Chipcon CC2420	250kbps, 2.6 MHz channel BW, 802.15.4 PHY	-90dBm @ PER =1% (or -88dBm @ BER =10^{-4}) Note: a 2dB offset is added to get the sensitivity @ BER =10^{-4}.
Nordic nRF24LU1+	2 Mbps, 2 MHz channel BW, GFSK 1 Mbps, 1 MHz channel BW, GFSK 250 kbps, <1 MHz channel BW, GFSK	-82dBm @ BER =10^{-3} (or -80dBm @ BER = 10^{-4}) -85dBm @ BER =10^{-3} (or -83dBm @ BER = 10^{-4}) -94dBm @ BER =10^{-3} (or -92dBm @ BER = 10^{-4}) Note: a 2dB offset is added to get the sensitivity @ BER =10^{-4}.
Freescale MC13202	250kbps, 2.6 MHz channel BW, 802.15.4 PHY	-92dBm @ PER =1% (or -90dBm @ BER = 10^{-4}) Note: a 2dB offset is added to get the sensitivity @ BER =10^{-4}.

Table 4 Example of ISM radio's that can be leveraged for MBAN

In summary, 0 dBm maximum transmission power for the 2360 - 2390 MHz band is sufficient to meet link robustness requirements of MBAN short-range applications.

Moreover, 0 dBm transmission power limit for the 2360 - 2390 MHz band can significantly alleviate possible in-band interference to incumbent users. Together with exclusion zones and frequency agility, the proposed 0 dBm transmission power limit can elegantly support the co-existence of MBAN and AMT systems. More technical details can be found in the exclusion zone part.

At the same time, a higher transmission power limit for the 2390 - 2400 MHz is preferred from home healthcare perspective. In a home monitoring case, a long communication range is highly desirable to provide greater mobility to users and minimize the required base installation cost. A maximum range of 10 meters is a reasonable design objective for home monitoring applications. Also, a higher power limit is needed to cope with an adverse event that may cause a patient to fall on the transmitter, causing significant signal attenuation. **In the following analysis, we propose 20 mW (i.e. 13dBm) transmission power limit for the 2390 - 2400 MHz band based on the link budget analysis below.**

In our link budget analysis, we assume AWGN channel model, 10 meter communication range, 0 dBi TX and RX antennas, free-space path loss, central frequency of 2400 MHz (worst case), 10 dB noise figure and 6 dB implementation loss. Since most of the home monitoring applications that require long ranges are usually low-rate applications, we assume the data rate is 31.25 kbps. Two mature modulation schemes are studied, O-QPSK and FSK. This analysis does not include excess noise from adjacent ISM devices. Table 5 summarizes the link budget analysis results.

Parameter	O-QPSK	FSK
Information data rate (R_b) [Kbps]	31.25	31.25
Average TX power (P_T)[dBm]	0	0
TX antenna gain (G_T)[dBi]	0	0
Center frequency (f_c) [MHz]	2400	2400
Path loss at 10 meter, $L_1 = 20\log_{10}\{(4\pi f_c d/(3\times 10^8))\}[dB]$	60.05	60.05
Human body blockage loss (L_2)[dB]	30	30
building attenuation (L_3)[dB]	20	20
RX antenna gain (G_R) [dBi]	0	0
RX power ($P_R = P_T + G_T + G_R - L_1 - L_2 - L_3$) at $10m$	-110.05	-110.05
Average noise power ($N = -174 + 10 * log_{10}(BW)$) [dBm]	-129.05	-129.05
RX noise figure referred to the antenna terminal (N_F) [dB]	10	10
Total noise power ($P_N = N + N_F$) [dBm]	-119.05	-119.05
Required Minimum SNR (S) [dB]	8.37	11.38
Implementation loss (I) [dB]	6	6
Link Margin ($M = P_R - P_N - S - I$), $d = 10$m [dB]	-5.37	-8.38

Table 5 Link budget analysis for MBAN in-home applications with 0 dBmTX power

In the above analysis, a 30 dB loss and another 20 dB loss are included to represent the human body blockage loss, which could happen when a patient falls on MBAN devices in an adverse event, and extra attenuation introduced by barriers (e.g. walls and doors), respectively. Some barrier attenuation values can be found in the online document [8] and 20 dB is a practical choice to cover typical use cases. From the above analysis, one can see that 0 dBm is not enough to provide a 10-meter communication range. For FSK based radio, the link margin is only -8.38 dB. Moreover, since the 2390 - 2400 MHz band is adjacent to the 2.4 GHz ISM band, some extra link margin is needed to counteract the interference from the out-of-band radiation of 2.4 GHz ISM band devices (e.g. high-power WiFi devices) in the home that could be in near proximity to the MBAN devices. Usually, a 3~5dB link margin would be enough. Increasing the transmission power to 13 dBm would provide sufficient link margin for home monitoring applications working in the 2390 - 2400 MHz band, as demonstrated by the following link budget analysis. Therefore, we propose to increase the transmission power limit to 13 dBm (20mW) for the 2390 - 2400 MHz.

Parameter	O-QPSK	FSK
Information data rate (R_b) [Kbps]	31.25	31.25
Average TX power (P_T)[dBm]	13	13
TX antenna gain (G_T)[dBi]	0	0
Center frequency (f_c) [MHz]	2400	2400
Path loss at 10 meter, $L_1 = 20\log_{10}\{\left(4\pi f_c d/(3\times 10^8)\right)\}[dB]$	60.05	60.05
Human body blockage loss (L_2)[dB]	30	30
building attenuation (L_3)[dB]	20	20
RX antenna gain (G_R) [dBi]	0	0
RX power ($P_R = P_T + G_T + G_R - L_1 - L_2 - L_3$) at $10m$	-97.05	-97.05
Average noise power ($N = -174 + 10 * log_{10}(BW)$) [dBm]	-129.05	-129.05
RX noise figure referred to the antenna terminal (N_F) [dB]	10	10
Total noise power ($P_N = N + N_F$) [dBm]	-119.05	-119.05
Required Minimum SNR (S) [dB]	8.37	11.38
Implementation loss (I) [dB]	6	6
Link Margin ($M = P_R - P_N - S - I$), $d = 10$m [dB]	7.63	4.62

Table 6 Link budget analysis for MBAN in-home applications with 13 dBm TX power

With this power limit, MBAN radios can provide reasonable coverage, medical-grade link performance, and data rates for home monitoring applications and overcome excess noise from nearby ISM devices. Since there is no critical incumbent users in this band, 13 dBm transmission power would not cause interference issues, especially with these low duty cycle devices. Also, with dynamic transmit power control techniques, MBAN radios would only use such power levels when needed. For example, users would stay in their houses most of the time and MBAN radios can significantly lower the transmission power since the building attenuation would be much less than 20 dB.

5. MAXIMUM EMISSION BANDWIDTH

A more flexible definition of maximum signal bandwidth would allow a greater capacity to manage evolving medical applications. A higher or flexible bandwidth would allow more applications and shorter duty cycles (that would reduce power consumption). If the Commission adopts a maximum signal bandwidth, Philips strongly encourages the commission to adopt a bandwidth limit of no less than 5 MHz (at 20 dB down).

5.1 A higher maximum authorized emission bandwidth would provide flexibility and technology neutrality, allowing industry to develop appropriate MBAN solutions, especially to leverage most of the available 2.4 GHz ISM band solutions to produce relatively low-cost MBAN devices.

As previously stated [3], the commercial acceptance of Medical Body Area Network Services (MBAN) will depend on manufacturers producing small low-cost (*e.g.*, low enough to be disposable in some cases) sensors. Doing so in turn will depend on the manufacturers' ability to leverage low cost, off-the-shelf integrated circuits that can be used directly or at least that can be modified or adapted at relatively modest cost and complexity (*e.g.*, minimal external discrete circuitry). One of the benefits of using the 2360-2400 MHz spectrum for MBAN systems is the capability to leverage multiple off-the-shelf 2.4 GHz short range connectivity solutions to achieve economies of scale. Some major 2.4 GHz ISM band connectivity solutions, which are commercially available and have been widely deployed, and their parameters, are listed below.

2.4 GHz Solutions	Emission Bandwidth (20dB bandwidth)	Supported Raw Data Rates
Bluetooth™	~1 MHz	1 Mbps (2 and 3 Mbps for enhance data rate modes)
ZigBee™	~2.6 MHz	250 Kbps
Nordic Semiconductors Proprietary solutions (i.e. nRF24L01+)	< 1 MHz for 250 Kbps mode ~1 MHz for 1Mbps mode ~2 MHz for 2 Mbps mode	250 Kbps 1 Mbps 2 Mbps

Table 7 Examples of available 2.4 GHz ISM technologies

For example, the estimated market size of Bluetooth devices is around 1400 million units for 2010 [10] and the estimated market size of ZigBee devices is more than 500 million units for 2010 [9]. Moreover, both Bluetooth and ZigBee have been adopted by the Continua Health Alliance as low power wireless solutions to provide interoperable personal health systems that empower people and organizations to better manage their health and wellness. A 1 MHz maximum emission bandwidth rule would exclude the possibility of leveraging some of the most successful 2.4 GHz low-cost short-range solutions, such as ZigBee, and other proprietary solutions from leading 2.4 GHz solution vendors. This would stunt technology innovation and development. On the other hand, allowing greater bandwidth, such as 5 MHz, would accommodate almost all of the current available 2.4 GHz low power connectivity technologies and result in low-cost and mature MBAN solutions.

5.2 Broader emission bandwidth creates flexibility to cater to the diverse needs of MBAN applications, especially high data rate and low power consumption needs.

MBAN applications have a large variety of requirements on data rate, link reliability, delay tolerance, and lifetime. A 5 MHz maximum emission bandwidth will provide scalable data rate modes to meet a wide range of requirements.

Technical parameters of several typical MBAN applications are shown in Table 8

Application	Target data throughput	P2P Latency	Application Bit Error Rate (BER)	Desired Battery Lifetime
ECG (Multi-lead)	96 Kbps	< 250 ms	$< 10^{-6}$	>1 week
EMG	384 Kbps	< 250 ms	$< 10^{-6}$	>1 week
O_2/CO_2/BP/ Temp/Respiration/ Glucose monitoring, accelerometer	< 10 Kbps	< 250 ms	$< 10^{-6}$	>1 week

Table 8 Some technical parameters of several typical MBAN applications

For example, a classic multi-lead ECG node may require as high as 96 kbps application level throughput to forward its ECG signal to a hub device in a real-time cardiac monitoring system while at the same time, the desired battery lifetime is more than a week. Assuming 25% duty cycle and 40% protocol overhead (including physical layer, MAC layer and application layer protocols), the required raw data rate should be at least 640 Kbps. For the EMG case, the required raw data rate should be at least 2.56 Mbps. In the future, the required raw data rates could be even higher to achieve better monitoring performance. To provide such a high data rate with a long battery lifetime (> 1 week) and a very low error rate, a broad maximum emission bandwidth is preferred. If a 1 MHz maximum emission bandwidth is adopted, a short-range wireless connectivity solution for MBAN applications would need to achieve 3 bits/Hz (or even higher in the future) spectrum efficiency. To design such wireless systems could be very challenging considering the strict link reliability and power consumption requirements since more sophisticated modulation and/or coding schemes are needed. This would increase MBAN device implementation complexity, the peak power consumption and also the average power consumption, resulting in it being impractical to use a small size battery or energy harvesting components in an MBAN device, which is especially undesirable for disposable sensor applications. However, for example, a 3 MHz emission bandwidth can relax the required spectrum efficiency to 1 bit/Hz, which could be achieved with very simple modulation schemes, like GFSK, FSK and offset-QPSK. Those modulation schemes are very mature and currently

widely used in Bluetooth, ZigBee and most of the 2.4 GHz proprietary solutions. Also it provides potential to further improve raw data rates to meet the requirements of future MBAN applications.

5.3 Broad emission bandwidth can significantly prolong MBAN device battery life via low duty cycle operations.

Battery life is an important factor to be considered when designing an MBAN system. A higher emission bandwidth (at least 3 MHz) enables MBAN devices to operate at higher data rate modes (~ 3 Mbps) and therefore achieve low duty-cycle operation. Low duty-cycle operation facilitates low average power consumption and long battery life. For example, the Nordic nRF24L01+ chipset has a power consumption of 34 mW (0 dBm transmit power) either with 1 Mbps (1 MHz bandwidth) or with 2 Mbps (2 MHz bandwidth) in the transmission mode, a power consumption of 39.3 mW with 1 Mbps and 40.5 mW with 2 Mbps in the receive mode, and a power consumption of 78 µW in the standby mode (standby-I mode). There is almost no difference between the 1 Mbps option and the 2 Mbps option in terms of average power consumption in their TX/RX modes. However, the 2 Mbps option can reduce the duty cycle almost by half and therefore double the battery lifetime compared to the 1 Mbps option.

5.4 Broad maximum emission bandwidth can provide medical-grade link reliability.

Data loss could cause severe problems in MBAN applications and usually strict link reliability is required. A higher emission bandwidth can provide medical-grade link reliability. A wide bandwidth could be used to achieve high spreading gain via spectrum spreading technologies or coding gain via simple channel coding while still maintaining a high enough rate to support MBAN applications. For example, simulation results of data rate modes are shown in Fig. 26. The 250 Kbps mode uses the direct sequence spectrum spreading (DSSS) scheme with Offset QPSK (O-QPSK) modulation, which is used in IEEE 802.15.4. The 500 Kbps mode uses the direct sequence spectrum spreading (DSSS) scheme with Offset QPSK (O-QPSK) modulation, which is utilized in IEEE 802.15.4b [11]. The 1 Mbps mode uses O-QPSK modulation with a ½-rate repetition code (repeat each symbol twice). The 2 Mbps mode just uses O-QPSK modulation. All the above four data rate modes have the same 20 dB emission bandwidth, which is around 2.6 MHz. From the simulation results, one can see the 250 Kbps, 500 Kbps, and 1 Mbps modes can achieve about 8.3 dB, 5.2 dB, and 3 dB signal-to-noise-ratio (SNR) gain at the bit error rate of 10^{-4} respectively, compared to the 2 Mbps data rate mode. This elegent performance-rate tradeoff can be used by a MBAN device to adaptively adjust its transmission to achieve medical- grade performance with low power consumption. When the link quality is good, an MBAN transmitter can use a high data rate mode to achieve low duty-cycle, therefore low power consumption; while when the link quality becomes worse, for example, due to patient body movement or interference from other system, an MBAN tranmitter can use a low data rate mode to achieve performance gain, thereby ensuring medical-grade quality-of-service.

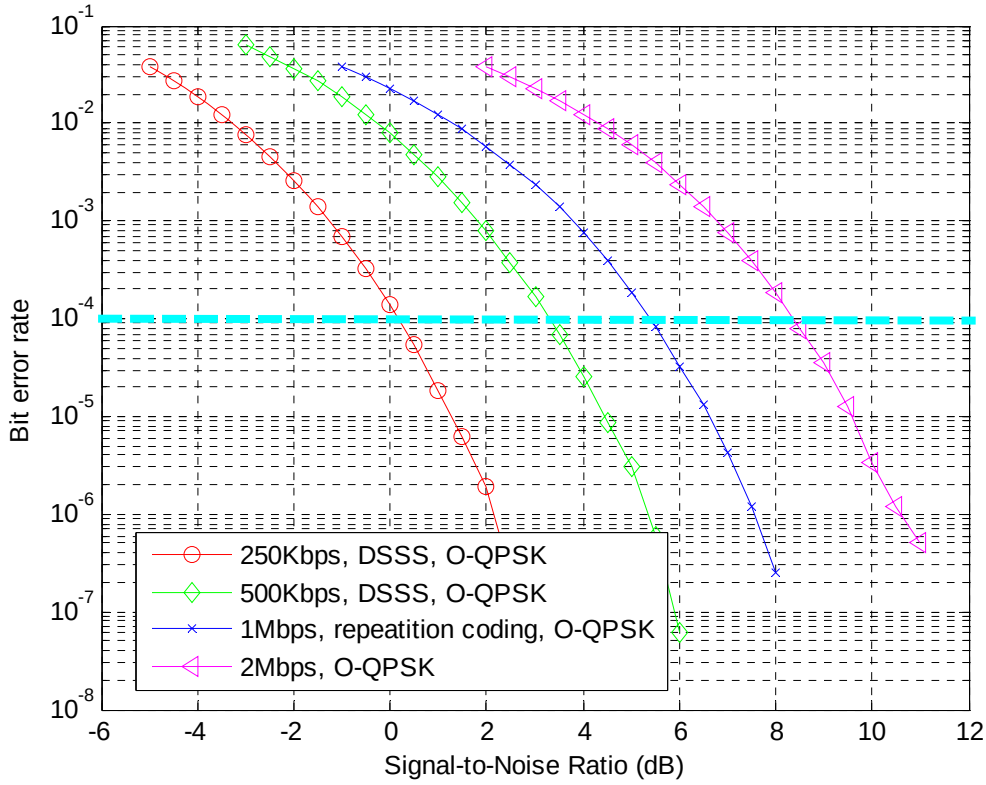

Figure 25 BER performance of O-QPSK with different data rates

Second, higher data rates (achieved with a wide bandwidth) enable MBAN devices to finish their transmission in a short period so that they can do retransmissions if needed in the same or other channels to mitigate the effects of external interference and channel fading while still maintaining the point-to-point (P2P) latency requirements.

5.5 Broad emission bandwidth can be used to improve co-existence among multiple MBAN devices and with the AMT systems.

First, low duty-cycle operation reduces the on-air time of MBAN devices and therefore reduces the possibility of interference to the AMT systems. This also enables multiple MBAN networks to co-exist in the same channel with a low collision possibility.

Second, a higher bandwidth can be utilized to achieve spreading gain so that a lower transmission power could be used, which in turn reduces the interference power to the AMT systems or other MBAN networks. This could improve the spectrum reuse efficiency.

Third, a 40 MHz spectrum will provide enough candidate channels for MBAN devices to migrate to if they detect interference from AMT systems or other MBAN networks even if a higher emission bandwidth is allowed. For example, if a channel spacing of 3 MHz is used, there would be 12 channels (assuming a 2 MHz guard band at each end) available for MBAN

operations. Even if a co-existing AMT system occupies 20 MHz, there would still be at least 5 channels available, which in most use cases is enough to support multiple MBAN co-existence with reasonable performance.

5.6 Broad emission bandwidth is feasible from practical implementation aspects.

An emission bandwidth higher than 5 MHz may complicate MBAN radio implementation, thereby increasing cost and power consumption. If an MBAN system has a bandwidth that is wider than the coherent bandwidth of typical MBAN channels, it would require a complicated equalizer to deal with possible multipath fading (or frequency selective fading) and thus increase cost. To obtain a simple implementation, it is preferable to adopt a maximum emmission bandwidth that is smaller than the coherent bandwidth of typical MBAN channels. Due to the proximity of the 2.4 GHz ISM band to the 2.36 - 2.4 GHz band, channel measurement results for the 2.4 GHz body area networks (BAN) in the literature can be used to study channel characteristics of MBAN channels. In [12] the authors conducted extensive measurements to study the channel coherence bandwidth of 2.4 GHz BAN channels under different scenarios. It is shown there that in most cases, the coherence bandwidth is no less than 5 MHz. That means that with a channel bandwidth of 5 MHz or less, the frequency selective fading effect is negligible and no equalizer is required. Therefore, 5 MHz is a good choice for the maximum emission bandwidth in the sense of simplifying MBAN radio implementation and reducing costs.

Moreover, a bandwidth that is too large usually requires a high sampling rate and signal processing speed, which could increase power consumption. Thus, a very large bandwidth is not desired for MBAN applications since a long battery life is a priority. A 5 MHz is usually acceptable for those low power applications. For example, a 802.15.4 radio has a bandwidth of 2.6 MHz while achieving reasonablly low power consumption.

In summary, 5 MHz maximum emission bandwidth provides a good balance of all the above implementation considerations. This allows for future advancement in technology.

6. CONCLUSIONS

Below are summarized recommendations from the analyses, simulations and arguments presented above:

1. A 40 MHz allocation for MBAN on a secondary basis would permit coexistence of AMT, amateur radio, radio astronomy and MBAN devices with minimal potential for interference and allow deployment of multiple MBAN networks in high-density applications.
2. An exclusion zone radius of 11.5 km to protect AMT receivers is more than adequate for a large variety of diverse environments and conditions, and is conservative.
3. A maximum transmit power of 0 dBm in the 2360–2390 MHz band and 13 dBm in the 2390–2400 MHz band will enable MBAN networks to provide reliability and quality of service under the adverse channel conditions that likely will be encountered with on-body radios.

4. A maximum bandwidth specification of 5 MHZ would enable the use of existing 2.4 GHz devices as well as leave room for innovations to accommodate increased data rate and lower power requirements in the future.

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