Analysis and Stochastic Modelling of Interference Patterns for Cellular Networks

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Abstract

The internet of things envisages to create a plethora of heterogeneous objects and machines interconnected to each other to form a global system of systems that will ease and simplify the human tasks in countless ways. The possibility of every object acting as node that transmits and receives data at every moment to be a part of an interconnected ecosystem puts tremendous stress on the existing wireless technology. This shifts the focus of existing wireless technology to model the flow of data from human generated type to the machine generated traffic. Considering that most of the machines transmit majority of data on the uplink and conditioned on their inaccessible and remote locations, the metrics for their efficient performance demand a change in the existing architectures. Power efficient and self-sustaining systems will guarantee optimum performance in the IoT environment. The translation of every device into a transmitting node will also introduce tremendous interference in the system and modelling the performance of such an in presence of interference is of utmost importance. Considering the spatial distribution of such devices will no longer be regular, the tools of stochastic geometry are exploited to model the interference and the impact on the various nodes in presence of the different strategies employed for the system like CDMA or FDMA. The project thus aims to analyze the strategies that ensure the optimum performance of machine to machine communication in presence of interference and derive values for certain key metrics. On the lines of this approach, the focus is to further develop a unified framework for modelling all the key performance metrics in presence of interference and ensure optimum performance of the IoT system.

Keywords

Internet of Things, Machine to Machine, Interference, Uplink, Stochastic Geometry, Power Control

I. Introduction

Robust and efficient machine to machine communication has been envisioned as the driving force for the rapid growth of the Internet of Things vision as IoT relies heavily on the proliferation of M2M communication. The IoT encompasses vertical silos raging from automation to industrial applications, from smart home appliances to intelligent surveillance systems. IoT brings diverse opportunities and innovation through the intelligent interconnection of billions of nodes in the form of smart devices with value-at-stake being estimated to more than 14 trillion dollars over the next decade [1]. This vision calls for emergence of devices, sensors and machines that can drive the IoT with minimum human intervention. The machine type communication (MTC) has traffic characteristics that differ significantly from the conventional human to human traffic. The machines transmit on regular basis or on random intervals and their data consists of packets with short payload length. Therefore, on a session level, the aggregated traffic is composed of multiple short-lived sessions. The machines usually have limited power budget, thus the power usage should be carefully included in the analysis in order to have sustainable applications. The devices are designed to be deployed in remote and often inaccessible locations with the aim to function with least maintenance runs. This introduces some characteristic features in these devices which will differ significantly from the human generated traffic. Some of these features are studied in [2]-[5] and it is evident that in most cases, wireless connectivity provides the most feasible and economical link between machines and the corresponding governing services.

A. Motivation

The term IoT dates back to 1999 [6] and the past decade has seen considerable traction around the term especially from research communities around the world. With technology giants venturing in this domain with General Electrics with the Industrial Internet [7] and Cisco Systems with the Internet of Everything (IoE) [8], the field is expected to make mammoth growth in the coming years. The current LTE network is mostly optimized for H2H communications and hence does not seem to be well suited for M2M communications [2][3]. Some of the key characteristics of M2M are rigid battery constraints, keeping in view their deployment in isolated locations such as underground tunnels, remote surveillance conditions etc. This requires for enhanced power saving measures such as robust turn on/off options specifically poised for device originated or scheduled applications. The sessions can be infrequent and discontinuous and thus it requires to have extended discontinuous reception optimized for delay-tolerant, device-terminated applications. The devices deployed in static locations will have very low mobility and thus will require less frequent Tracking Area Updates (TAUs) and measurements customized for low-to zero-mobility M2M applications. The work in [9] presents a unified framework that highlights the power and energy efficient design for the M2M regime. The power strategy that employs data transmissions via common channel permits more efficient transition between states. The work in [9] also highlights the optimal resource allocation strategies and the benefits of employing CDMA scheme for efficient payload handling for the uncoordinated power strategy.

Another feature is that the uplink to downlink ratio is much higher for M2M traffic compared to traditional cellular traffic (where the dominant traffic is the downlink one).The realization of multiple nodes transmitting on the uplink at the same time also introduces an aggravated version of interference that needs to be handled effectively to allow the smooth and error free traffic flow. Thus with increased nodes and M2M sessions, an effective interference handling mechanism is also essential and the modeling of all the important system parameters such as the optimal power need to be determined in the presence of this interference.

II. Related Work

The M2M nodes will be deployed in an irregular pattern and thus conventional grid pattern modelling will fail to capture the exact performance effects. The tolls of stochastic geometry can be utilized in such a case by modelling the locations of the nodes as realization of a Poison Point Process PPP in the Euclidian space. The interference needs to be modelled for the uplink in the presence of multiple other nodes (UE) which will span across different adjacent cells. The work in [10] provides an excellent approach to model the uplink interference for the case of PPP distribution of Base stations and the UEs. For the case of M2M, the approach can be similar where the M2M nodes can be modeled as the UEs and the central governing nodes as the base stations. In the case of FDMA scheme, the interference will stem from the UE in the adjacent cells operating on the same frequency as the target UE. The concept of the frequency reuse within the cell is also important as it affects the number of active interferes and is studied from the following literature [11]-[13]. For random access at lower payloads the results in [9] indicate that the CDMA and FDMA scheme show similar performance and thus any of the schemes may be employed. For ease of implementation, the CDMA random access may be preferred at low to moderate arrival rates due to the apparent simplicity of the resulting system design and thus be used to establish uplink connection by sending small payload containing only the control information. This is suitable for uncoordinated strategy and thus with CDMA, the impact of power control needs to be in incorporated in the modelling of uplink interference. For CDMA analysis, the interference is studied from [14]-[15] using distributed power algorithm and robustness of the pseudo random codes in providing absolute orthogonality for accurate detection at the receive using [16]-[22]. From the literature study, the paper is organized as follows: Section III covers the basic system setup and the assumptions, interference modelling for the uncoordinated power scheme and the deriving the expression for optimal power. Section IV sets up the simulation paradigm to validate the analytical results with the simulation plots. Section V analyses the results for the plots and the comparison between the uplink and downlink characteristics of interference. Section VI summarizes the conclusions and highlights the scope for future work to develop a unified framework on these lines.

III. Proposed Model

A. System Setup

In this work, the locations of the base stations and the mobile users are modelled as a homogeneous two dimensional PPP in the Euclidian plane. The density of the mobile users λ_k is assumed to be greater than the density of the Base Stations λ so that it ensures every base station is connected to at least one user at a time and ensures a fully loaded condition. The baseline assumption is that a mobile user is connected to its nearest base station corresponding to an association function of max-received power averaged over fading effects. The work neglects the effect of shadowing and assumes only the case of Rayleigh fading which is benign for most real world fading situations. This follows that each base station is uniformly distributed in the voronoi cell of it corresponding user. The distance of the mobile user from its closes base station is denoted by r_o. The analysis begins by randomly choosing a base station from the set of all base stations to avoid the case of choosing a base station from a uniform distribution which will tend to be biased for the location of the base station more susceptible to lie in the bigger voronoi cell. Thus the random selection avoids this bias towards the occurrence of being in the bigger cells. From previous work [10] it is easily proved that this method of base station selection is tight in the context of deriving the values of optimum performance metrics. The distance of the user from the base station is a random variable r_o such that $r_o \in R$. The cells are this in the fully loaded condition such that the BS at every time slot is connected to at least a UE. This situation is captured in figure 1.

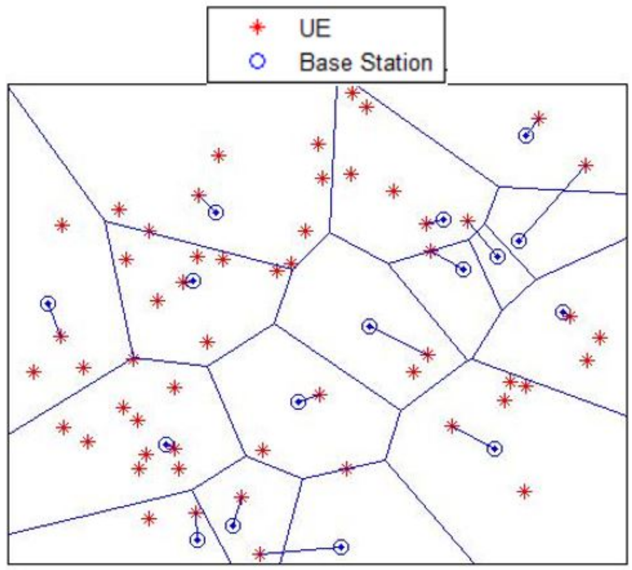

Fig. 1: Voronoi Cells with Base Station UE association

The analysis is focused on the uplink for modelling the interference and calculating the values of the optimum power. The arrival of data is assumed as a Poisson Process with mean λ , consisting of packet transmission requests in each time slot as $N_a = Pois(\lambda\tau_s)$ where τ_s denotes the time slot of each transmission. For simplicity, the current work only considers the case of one step transmission and the case of retransmission or any transmission lasting more than τ_s are not considered. Ideally a retransmission strategy will increase the overhead of the system and thus it is a better approach to just consider a step transmission. Each packet is assumed to have a payload consisting of L bits. For all M2M communication, the value of L will be limited to maximum of 1000 bits as M2M consists of short payload sessions. The intra cell interference is assumed to be zero as the different UE exhibit perfect FDMA and the deteriorating impact of interference stems from the other cells. The analysis considers only one type of cell namely a microcell although the future work can be modeled for the case of hetnets.The schematic in figure 2 shows the packet transmission as a function of the bandwidth W and the time slot τ_s. Once a UE camps on to a particular BS after going through the LTE initial access scheme, the next step is to initiate the strategy for accessing the data which is discussed in the following

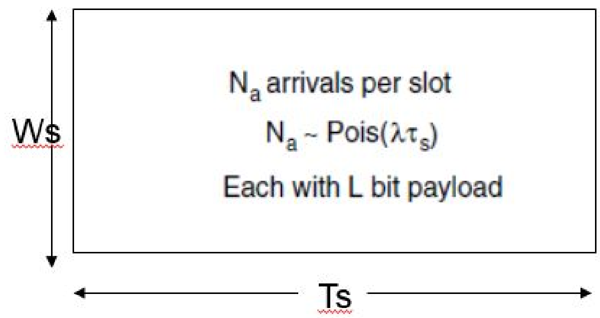

Fig. 2: Illustration of the time-frequency resourceslice

section.

B. Access Mechanism

The majority of machine to machine sessions take place on the uplink and usually consist of shorter sessions of fewer bits rather than the conventional sessions of longer payload. The machines need to be constantly within the scan of the central controlling node and keep updating the data metrics such as a tunnel deployed water flow measuring machine, or a mall deployed customer check machine etc. M2M traffic is generated from various other sources such as home automation systems like the 'nest', smart traffic monitoring systems, smart electrical meters, filed deployed sensors etc. Most of these transmissions take place on the uplink however downlink transmissions maybe required when the controlling node requires to perform timely updates or broadcast important system check details. The traffic from these M2M devices has been studied in literature previously [23][24][25]. For purposes of power optimization it is essential to have the machines on extended discontinuous reception cycles. This implies the data will be sent at infrequent intervals and that M2M devices usually generate a short burst of traffic at relatively long inter-arrival time periods. This inter arrival time (IAT) can be fixed or deterministic. The device when not transmitting is in the IDLE state and does not have dedicated bearers or resources. In this low power state, the UE periodically listens to upcoming paging messages and then undergoes a transition from RRC IDLE to RRC CONNECTED state in which it does active exchange of data. The power strategy for access thus needs to be optimum suited to such needs of infrequent and shorter payload data transmissions. The framework described in

[9] provides two optimal strategies for transmission. The two are classified as Coordinated and Uncoordinated strategy wherein i) uncoordinated: the devices transmit data using slotted random access and there is no need to establish dedicated radio bearers, and ii) coordinated: the devices transmit data in a separate scheduled transmission. The figure illustrates the one step and the two step access mechanism. The access is enabled by the beacon that sends the information from the base station at the beginning of each time slot. The uncoordinated requires just a one step procedure to transmit the payload together with the control information.

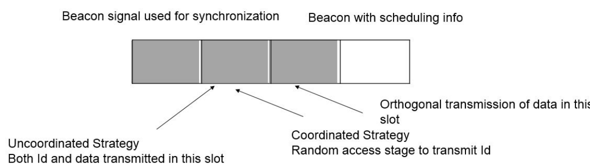

Fig. 3: Illustration of the One Step and Two Step Access Mechanism

The transmission power and other parameters are decided on basis of the information sent by the beacon at the start of each time slot. The value of data here typically consists of 1000 bits that consists of payload and the control information. The coordinated strategy requires the first step to transmit the control information requesting the dedicated resources to then transmit the actual data in the second step. This requires overhead on the downlink for transmitting the scheduling information. For the current analysis, a strategy suited for low payload but fast access is required and uncoordinated strategy best matches the requirement. The promising work carried out in [8] indicates that both the strategies show equal performance for lower values of payload while the coordinated outperforms uncoordinated for higher payloads. For M2M purpose, the uncoordinated serves as the best match.

C. Modelling Uplink Interference

For any UE in a voronoi cell, the distance of any UE from its BS r_o in the uplink is Poisson distributed. This link suffers from Rayleigh fading and path loss given by the attenuation factor α. The analysis considers robust power control strategy employed by each Base Station for its respective UE and thus requires to consider the distance of every UE from its own home BS d that performs the power control.The power control mechanism can be either fractional when the power control parameter ε takes values between $0 < \varepsilon < 1$ or is full power control for $\varepsilon = 1$.

The value of $\varepsilon = 0$ corresponds to all UE transmitting at the same power. The received power at a BS from a UE is thus given as
$P_r = P_{opt} g r_o$
The metric which determines the quality of a link is the received SINR[26][27].The extensive uplink analysis is done in [nov paper] and similar approach is used in the given work to model the uplink interference for an uncoordinated power transmission scheme employing power control.The interference stems from the UE in the adjacent cells that are operating on the same frequency as the uplink for the target UE and the given BS.The distance of every UE from the target BS is given by r_z.The random variables $r_z Z$ are identically distributed but not independent in general. The dependence is induced by the structure of Poisson-Voronoi tessellation and the restriction that only one base station can lie in each Voronoi cell. This arises from the basic assumption that a voronoi cell forbids the presence of two Base stations within the same cell.

The value of interference is thus given as

$$I = \sum g_z r_z^{-\alpha} d_z^{\alpha\varepsilon}$$

The distances r_z and d_z are Poisson distributed and the system setup is as shown in the following figure. The optimum value of the power needs to be calculated that will give an estimate of the optimum power given the constraints of achieving a specific spectral efficiency for the target uplink. Considering that L bits are needed to be transmitted in τ_s for an allocated bandwidth of W the spectral efficiency is given as $\frac{L}{W\tau_s}$
The analysis begins with the UE selecting the Base Station nearest to it at a distance r_o. The noise power is assumed to be additive and constant with value σ^2 but no specific distribution is assumed in general. The density function stems from the fact that no other BS is closer to given UE than the target BS. In other words, all interfering UEs must be farther than r_O. The probability density function (pdf) of r_o can be derived using the simple fact that the null probability of a 2-D Poisson process in an area A is exp$(-\lambda A)$
$P(r > r_o)$=P[No UE closer to BS]
$P(r > r_o) = exp(-\lambda\pi r_o^2)$
Therefore, the cdf is $P(r < r_o) = 1 - exp(-\lambda\pi r_o^2)$
The pdf can be found as

$$f_{Ro}(ro) = e^{-\lambda\pi r_o^2} 2\pi\lambda r_o$$

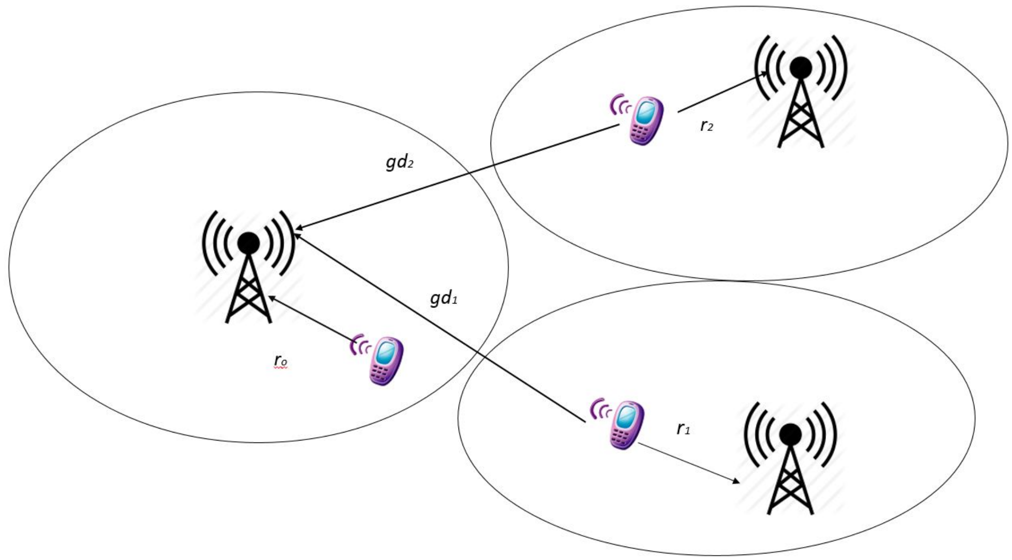

Fig. 4: Visual representation of Inter Cell Interference for the UE and its serving Base Station

The next crucial step is to find the expression for the optimum power given the constraints of a spectral efficiency and in presence of inter cell interference. The SINR received at the target BS and the spectral efficiency are related according to Shannons Capacity Theorem given as

$$\frac{L}{WTs} = \log 2(1 + SINR)$$

$$SINR = \mu = \frac{P_{opt} g {r_o}^{-\alpha}}{\sigma^2 + I}$$

$$I = \sum g_z r_z^{-\alpha} d_z^{\alpha\varepsilon}$$

$$P_{opt} = \frac{(2^{\frac{L}{WTs}} - 1)(\sigma^2 + I){r_o}^{\alpha}}{g}$$

$$P_{opt} = \int_{ro>0} P(P_{opt} > P_{max}) f_{Ro}(ro) dr$$

$$= \int_{ro>0} P(g < \frac{(2^{\frac{L}{WTs}} - 1)(\sigma^2 + I){r_o}^{\alpha}}{P_{max}}) f_{Ro}(ro) dr$$

The channel suffers from Rayleigh fading $g = exp(u)$ where g is i.i.d. exponentially distributed with mean $1/u$

$$P_{opt} = \int_{ro>0} 1 - exp(\frac{-u(2^{\frac{L}{WTs}} - 1)(\sigma^2 + I){r_o}^{\alpha}}{P_{max}}) f_{Ro}(ro) dr$$

$$P_{opt} = \int_{ro>0} P(\frac{(2^{\frac{L}{WTs}}-1)(\sigma^2+I){r_o}^{\alpha}}{g} > P_{max}) f_{Ro}(ro)dr$$
$$= \int_{ro>0} P(g < \frac{(2^{\frac{L}{WTs}}-1)(\sigma^2+I){r_o}^{\alpha}}{P_{max}}) f_{Ro}(ro)dr$$
$$= \int_{ro>0} 1 - exp(\frac{-u(2^{\frac{L}{WTs}}-1)(\sigma^2+I){r_o}^{\alpha}}{P_{max}}) f_{Ro}(ro)dr$$
$$f_{Ro}(ro) = 2\pi\lambda e^{-\lambda\pi r_o^2} r_o$$
$$P_{opt} = \int_{ro>0} 1 - exp(\frac{-u(2^{\frac{L}{WTs}}-1)(\sigma^2+I){r_o}^{\alpha}}{P_{max}}) 2\pi\lambda e^{-\lambda\pi r_o^2} r_o dr$$
$$P_{opt} = \int_{r_o>0} 1 - exp(\frac{-u(2^{\frac{L}{WTs}}-1)(\sigma^2){r_o}^{\alpha}}{P_{max}}) L_I(\frac{-u(2^{\frac{L}{WTs}}-1){r_o}^{\alpha}}{P_{max}}) 2\pi\lambda e^{-\lambda\pi r_o^2} r_o dr$$
$$L_I(\frac{u(2^{\frac{L}{WTs}}-1){r_o}^{\alpha}}{P_{max}}) = exp((\frac{-u(2^{\frac{L}{WTs}}-1){r_o}^{\alpha}}{P_{max}}) \sum_{i\in\phi} g_i x_i^{-\alpha} z_i^{\alpha\varepsilon})$$
$$L_I(s) = E_{I_i}[-exp(\sum_{i\in\phi} g_i s x_i^{-\alpha} z_i^{\alpha\varepsilon})]$$
$$= E_{I_i,x_i,z_i}[(\prod_{i\in\phi} exp(-g_i s x_i^{-\alpha} z_i^{\alpha\varepsilon}))]$$
$$= E_{x_i,z_i}[(\prod_{i\in\phi} E_{g_i} exp(-g_i s x_i^{-\alpha} z_i^{\alpha\varepsilon}))]$$
$$= E_{x_i}[(\prod_{i\in\phi} E_{z_i} exp(\frac{u}{u + s x_i^{-\alpha} z_i^{\alpha\varepsilon}}))]$$

Using the property of *pgfl* for PPP [28],

$$L_I(s) = exp(-2\pi\lambda \int_{x_i>r_o} (1 - exp(\frac{u}{u + s x_i^{-\alpha} z_i^{\alpha\varepsilon}}))xdx$$
$$L_I(s) = exp(-2\pi\lambda \int_{x_o>r_o} (1 - \int_{z_i>0} exp(\frac{u}{u + s x_i^{-\alpha} z_i^{\alpha\varepsilon}})) f_Z(z)dzxdx)$$

Considering the case of Rayleigh distribution for the distance z of each UE from it's home BS

$$f_Z(z) = 2\pi\lambda e^{-\lambda\pi z^2} zdz$$
$$L_I(s) = exp(-2\pi\lambda \int_{x_o>r_o} (1 - \int_{z_i>0} exp(\frac{u}{u + s x_i^{-\alpha} z_i^{\alpha\varepsilon}} 2\pi\lambda e^{-\lambda\pi z^2} zdz))xdx)$$

The expression for the case of Uniform PPP takes the form

$$f_Z(z) = 2\pi\lambda zdz$$

$$L_I(s) = exp(-2\pi\lambda \int_{x_o > r_o} (1 - 2\pi\lambda \int_{z=0}^{\frac{1}{\sqrt{\pi\lambda}}} exp(\frac{u}{u + s x_i^{-\alpha} z_i^{\alpha\varepsilon}}))zdzxdx))$$

where for $\alpha = 4, \varepsilon = 1$

$$L_I(s) = exp((\frac{-\pi\lambda r_o^2}{2}) + (\frac{\pi^2\lambda^2 {r_o}^2 \sqrt{P_{min}}}{2\sqrt{2^{\frac{L}{WTs}} - 1}})(arctan(\frac{\sqrt{2^{\frac{L}{WTs}} - 1}}{\pi\lambda\sqrt{P_{max}}})) - \frac{r_o^2\sqrt{2^{\frac{L}{WTs}} - 1}}{2\sqrt{P_{min}}} arctan(\frac{\pi\lambda\sqrt{P_{max}}}{\sqrt{2^{\frac{L}{WTs}} - 1}}))$$

$$P_{opt} = \int_{ro>0} 1 - exp(\frac{(2^{\frac{L}{WTs}} - 1)(\sigma^2){r_o}^{\alpha}}{P_{max}}) L_I(s) 2\pi\lambda e^{-\lambda\pi r_o^2} r_o dr$$

$$L_I(s) = exp((\frac{-\pi\lambda r_o^2}{2}) + (\frac{\pi^2\lambda^2 {r_o}^2 \sqrt{P_{max}}}{2\sqrt{2^{\frac{L}{WTs}} - 1}})(arctan(\frac{\sqrt{2^{\frac{L}{WTs}} - 1}}{\pi\lambda\sqrt{P_{max}}})) - \frac{r_o^2\sqrt{2^{\frac{L}{WTs}} - 1}}{2\sqrt{P_{max}}} arctan(\frac{\pi\lambda\sqrt{P_{max}}}{\sqrt{2^{\frac{L}{WTs}} - 1}}))$$

This expression gives the value of the Optimum power that a UE needs to transmit in wake of the interference and with the aim to achieve a specific spectral density to support the uncoordinated power strategy. The threshold value taken is that of P_{max} which indicates the maximum power that a UE is capable of transmitting. The probability that value of P_{opt} ¿ P_{max} indicates an outage event where the requirement of optimum power exceeds the maximum transmitting capability of the UE. The optimum power value thus helps to study the trends of its variation as a function of the P_{max} to determine efficient metric for effective M2M. The next step is to now check the validity of the analytical result with the simulation setup.

IV. Simulation Setup

The setup tries to emulate the poisson model with the spatial distributions of the base stations and the UEs in the space as a realization of a homogeneous PPP. The value of the spectral efficiency is calculated with L= 1000 bits τ_s= 1sec and the bandwidth W =1 Mhz. The UE are distributed as PPP with density much higher than that of the base stations. The voronoi tessellation for each UE-BS association is as shown in the following figure. The fading is modeled as Rayleigh for each of the uplink association. A UE is chosen at random and the BS nearest to it as calculated. Now taking this UE-BS link as the uplink under consideration, the interference will modeled as emerging from other UEs. Here it is not practical to consider all the UE for interference as in reality at one time slot only one UE from each cell will be transmitting at the given uplink frequency and only this will add to interference. Thus it is essential to establish associations of all BS to their nearest UE so that these active UE will be useful for the analysis.

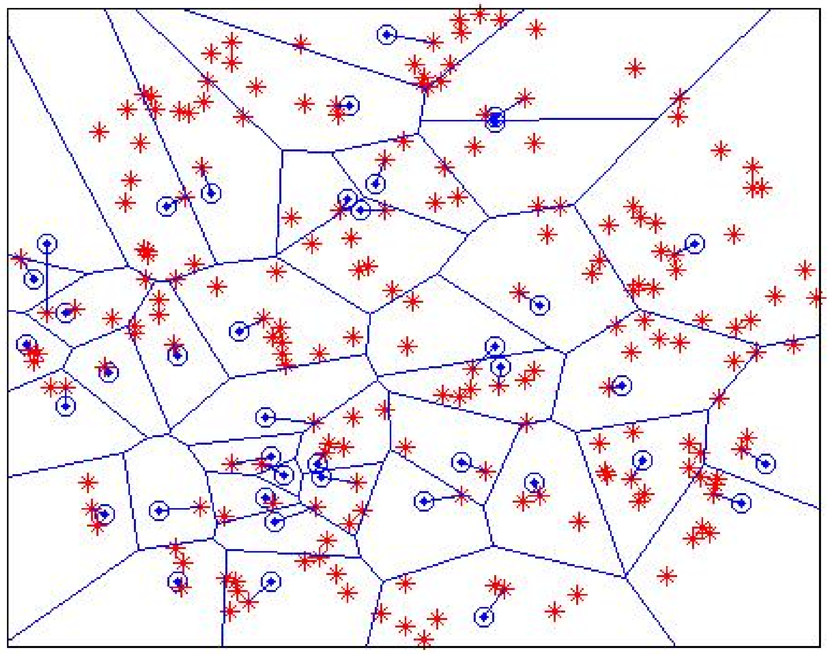

Fig. 5: Voronoi Tessellation for the UE and its serving Base Station in the Simulation Setup

All other UE which are not camped on to any BS at this particular instant are in an inactive mode, that is in other words they are not operating on the same uplink frequency. This concept is applied in the simulation set up and the active UE are now available for analysis. Ideally to implement Power control, the distances of all UE from their serving home BS can be calculated and then the value of the power control parameter ε can be used to find power of each UE. In reality the value of ε will be variable for the different UEs and also be correlated to their distances from the target BS as r_z in reality are not uncorrelated or independent. Thus to incorporate the effect of variable ε, the powers can be generated in a probabilistic way and then the cumulative effect can be incorporated to find the value of interference. Each of the link is also modelled for the Rayleigh fading and then using threshold of the P_{max} value the outage is calculated to find the value of P_{opt}. The impact of noise on the setup is analyzed and the two curves are approximately same which shows the impact of noise can be neglected and the network can be considered as an interference limited network. The following figure summarizes these conclusions. Taking the

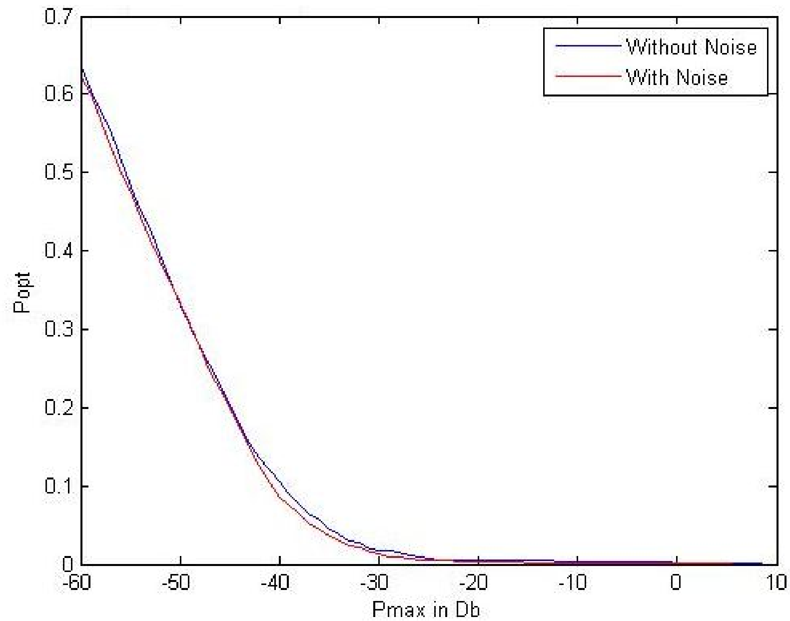

Fig. 6: Impact of Noise on Network

value of base station density λ to be λ=0.25 the simulation is carried out and the result in figure 7 is obtained. It is evident from the plot that the analytical value shows a higher value than the

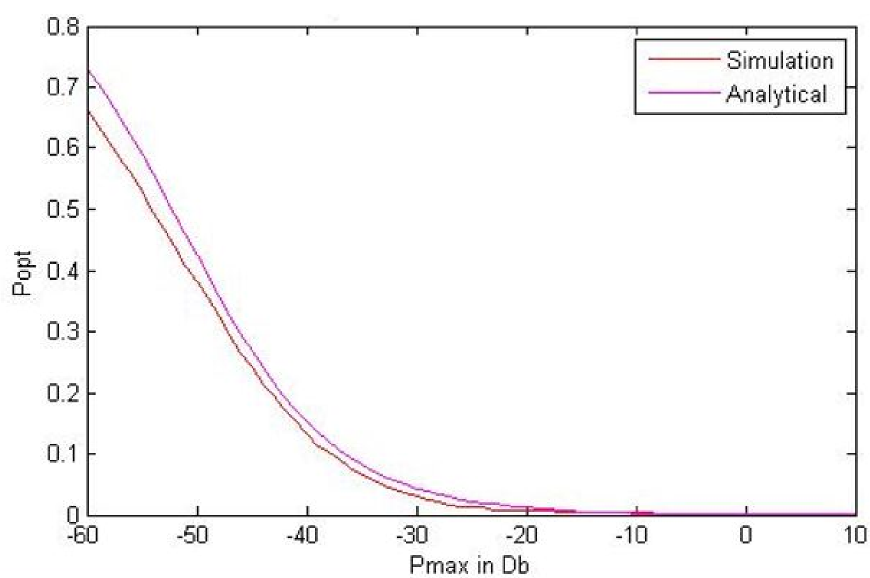

Fig. 7: A plot of the uplink Optimum Power for a PPP network for $\lambda = 0.25\varepsilon = 1$

simulation value and the gap is also high. On careful visualization of the setup, it is found that multiple BS connect to the same UE which violates the condition and introduces this gap. This observation is captured in figure 8. The condition that no two BS can connect to the same UE

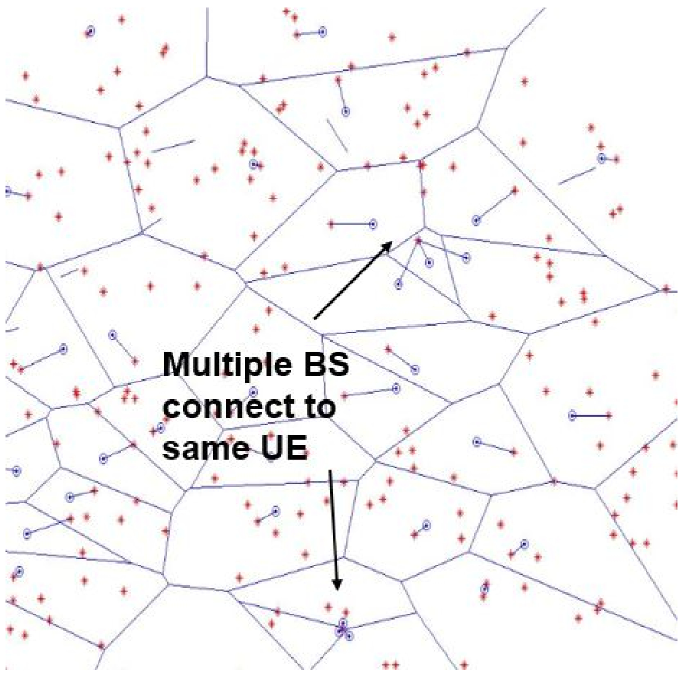

Fig. 8: Illustration showing multiple BS connecting to same UE

is now introduced and the two curves for the analytical and the simulation values come closer as shown in the following figures.

V. OBSERVATIONS AND RESULTS

The final plot comparing the result between the analytical and the simulation values for the expression of optimal power is as shown in the figure. The value of R_z is assumed to be independent in the analysis but this not the case in reality as the placement of UE from the target Base station does have some correlation which will not make the process an i.i.d one. Thus the curves may continue to show some gap and a tighter approximation may be required. One of the reasons the two curves do not give a tight approximation is mainly because the effect of every UE connecting to its nearest BS is not captured in this setup. In real world systems, the downlink and uplink take over the same link between the UE and the BS and thus the BS

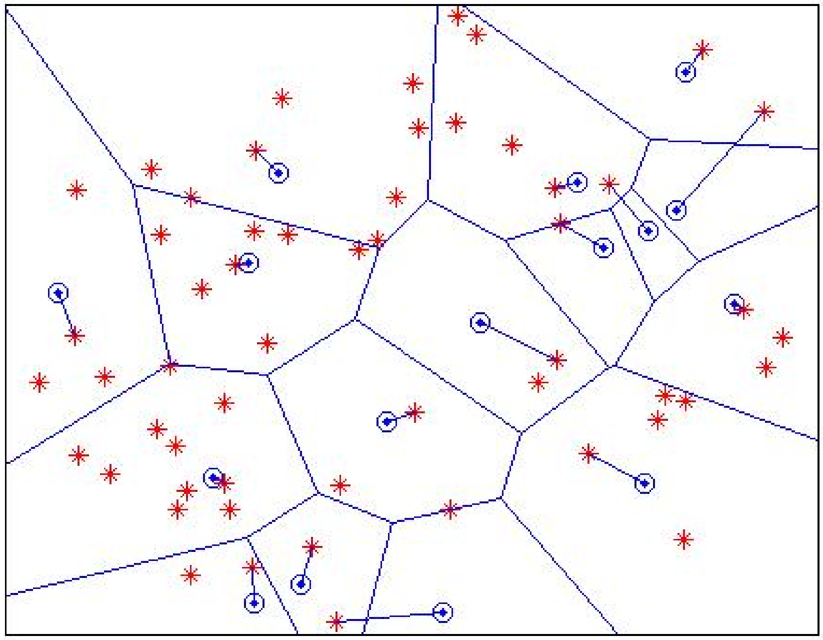

Fig. 9: Voronoi Tessellation having singular UE and BS association links

gets precedence in choosing the nearest UE which does not necessarily include the case of UE being in association to the closest BS. The other reason can be the assumption in the analytical setup that assumes every interferer is at a distance greater than the closest UE. In reality and simulation this need not be true as can be seen from the anomaly captured in the following figure. The BS in Cell 2 has its nearest UE which is already camped onto the BS in Cell 1 and hence this BS connects to the nearest UE within its own cell 2. Nevertheless, the interferer is at a closer distance than the serving UE. This case is eliminated in the analytical setup by assuming the condition $x_i > r_o$. The next observation to be analyzed is that the interference in uplink is higher than the downlink and this is the reason that the plot for uplink shows lower coverage than the downlink as seen from the figure. The following figure shows the plots for Coverage Probability for value of λ =0.25.

One of the reasons for this gap is the power transmitted in downlink is uniform for all users while in uplink the transmit powers are different. The conventional system follows the same

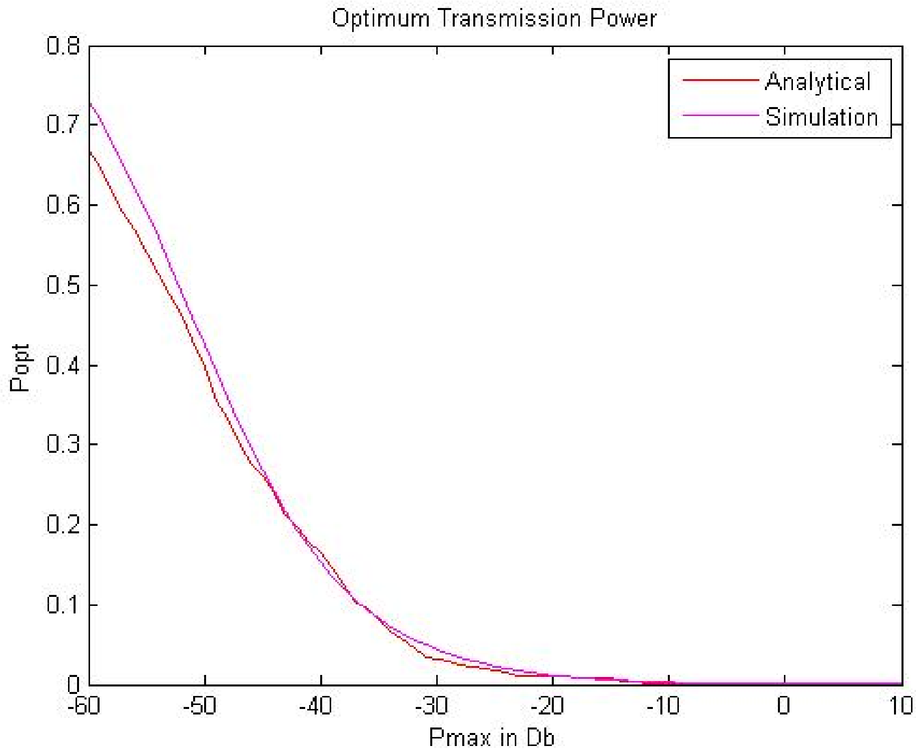

Fig. 10: A plot of the uplink Optimum Power for a PPP network for $\lambda = 0.25\varepsilon = 1$

association for the uplink and the downlink. In this case the uplink interference is a function of many parameters such as the UE transmissions in different cells, which in turn depends on location of that UE from its own home base station, level of power control employed and the distance from the target base station. Contrary to this in downlink, the interference is only dependent on the BS transmit power and the distances of the different BS from the target UE.In such a case due to the diverse nature of the two links and a more involved analysis of the uplink, it may be a better solution to decouple the uplink and the downlink that may serve as efficient way to tackle and model the two interferences.

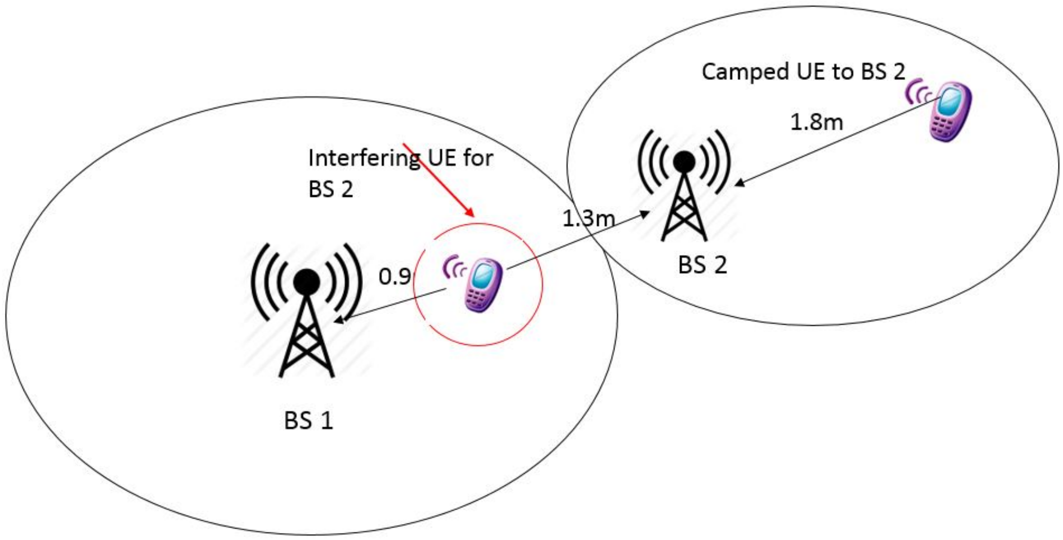

Fig. 11: Illustration when the interfering UE is closer than the camped UE for a BS

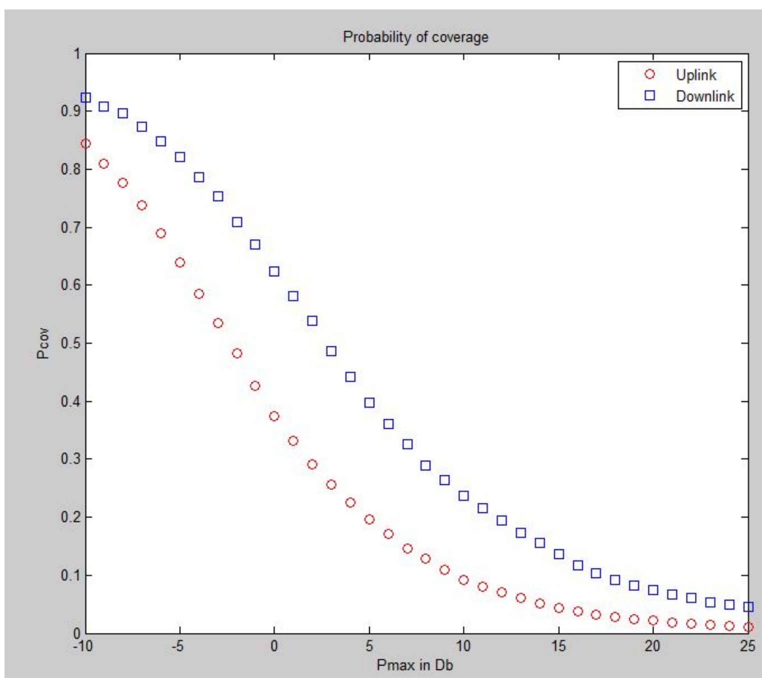

Fig. 12: Plot for P_{cov} for Uplink and Downlink for $\lambda = 0.25$

VI. CONCLUSION

The work analyzed the current trends for efficient M2M and modelled the uplink transmit sessions from the nodes in presence of interference from the adjacent cells. The setup was modelled using tools of stochastic geometry and the stochastic analysis and modelling of interference was achieved for the cellular network to ease the process of MTC. The different strategies for power transmission were studied and the value of the optimum power was derived for the uplink M2M sessions using uncoordinated power strategy. The analysis of the simulation and the analytical plots indicated the shortcomings due to the diverse nature of the uplink and the downlink interference patterns. The establishment of independent associations for the uplink and the downlink would aid to have efficient modelling for the uplink substantially help to generate an interference environment more suitable for the uplink transmissions. This would prove to be a major advantage to the M2M sessions which mostly take place on the uplink.The analysis and value of optimum power calculated in the given work will help to design power efficient M2M system with a known value of spectral efficiency. Since the approach considers the maximum interference scenario, once the device maximum power is known it is easy to establish bound for the value of optimum power.

The IoT ecosystem can be made more robust by ensuring error free communication between its member nodes and devices. This is the first step in realizing the future goal of devising a smart and adaptive system that integrates the coordination of data from various devices and controls the scenarios in an effective and intelligent manner with minimum human intervention. Considering the large number of smart devices that will be a part of the IoT network, the system should be tolerant to interference from the surrounding nodes of the IoT ecosystem. The future work thus involves a more involved study for deriving the values of optimum metrics for case of retransmissions, for the case of heterogeneous network , subsume the effect of shadowing in the interference analysis and to capture the effects of dynamic power control [29].

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VII. Tasks Achieved

This additional section correlates the tasks finally achived to the initial aims listed in the project proposal.

A. Achieved

1. Study of current interference modelling techniques for Homogenous and Heterogeneous Networks

2. Study of Point Process Theory and Stochastic Geometry Approach to analyze the randomness and irregularity of the currently deployed wireless networks.

3. Calculate the value of SINR and interference as a Rayleigh Fading from the surrounding base stations that aid in calculation of Probability of success and outage.

4. Study the value of the interference metrics for FDMA scheme

This was incorporated in the process of deriving the P_{opt} value by considering the SINR on basis of FDMA scheme.

5. Estimate the robustness of CDMA scheme in presence of fading and interference

The power control was incorporated in the analysis and so was the literature related to CDMA failure probability studied from [9].

B. Slight Deviation

1. Determine the expression for the maximum achievable rate using the value of SINR

For the case of optimum performance metric, the value of Optimal power was a better measure than the maximum achievable rate for the application in M2M scenario in uncoodinated strategy.