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Service Architecture Selection for Multimedia Broadcast/Multicast Services

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***Abstract* -** Multimedia broadcast/multicast service (MBMS) is one of the important services for 4th generation wireless communication systems. In this paper, we proposed a service architecture selection algorithm to find the best service architecture that maximizes the spectral efficiency of MBMS. Analytical models were presented to derive the average mutual information and the average spectral efficiency of each cell for different service architectures. The analytical models were developed based on the number of subscribed users in each cell and the intended MBS coverage requirement. Based on a given requirement, each cell then selects a suitable service architecture to maximize the overall spectral efficiency of the network. Simulations were conducted to verified the effectiveness of the proposed service architecture selection algorithm.

***Keywords*:** Multimedia Broadcast/multicast Service (MBMS), Service architecture, Mutual information, Spectral efficiency.

1. Introduction

Multimedia broadcast/multicast services (MBMS), which is also known as multicast and broadcast service (MBS) in IEEE 802.16m, is one of the important services defined by 3GPP Long Term Evolution (LTE) for the 4th generation cellular systems. MBMS is a point-to-multipoint service where data packets are transmitted simultaneously from a single source to multiple destinations (Vartiainen *et al.*, 2007).

In MBMS, the same data is transmitted via a common broadcast or multicast channel to multiple *MBS subscribers (MSs)*. Two service architectures were supported in 3GPP for delivering MBMS services: single cell-point to multi-points (SC-PTM) and multicast broadcast single frequency network (MBSFN). In SC-PTM, each base station (BS) transmits MBS content using its own modulation coding scheme (MCS). In MBSFN (or SFN in IEEE 802.16m), multiple BSs are synchronized to transmit the same MBS content over the same frequency channel at the same time using the same MCS.

The best service architecture to delivery MBS is highly dependent on the average number of MSs in a cell (3GPP R1-072637, 2007). Simulations were conducted to investigate the spectral efficiency for wideband code division multiple access (W-CDMA) systems. The results indicated that SC-PTM becomes the best choice if there is more than on MS in a cell. The MBSFN with soft combining results in the highest spectral efficiency if the average number of MSs in a cell exceeded a certain value. Up to now, no theoretical study/simulation result was presented for guiding the operator to select the best service architecture in 802.16m or LTE. In LTE, it adopts an orthogonal frequency division multiple access (OFDMA) scheme and may utilize the decode-and-forward relay technology to enhance the coverage or spectral efficiency (Peng *et al.*, 2010). Hence, the study needs to consider the effect of cyclic prefix (CP) in OFDMA to investigate the macro diversity gain of MBSFN. Moreover, the study has to take the new service architectures resulted from the newly introduced relay stations (RSs) into design consideration. That is, two new service architectures of relay-enabled SC-PTM (R-SC-PTM), and relay-enabled SFN (R-SFN) may be used for MBS transmission. In R-SC-PTM and R-SFN, MSs can receive signals transmitted from the BS and RSs at a higher speed or with a better signal quality. However, the price paid for the enhanced performance is the cost of extra transmission time from the BS to RS.

This paper presents an analytical model for the network operator to select the best service architecture for delivering MBMS. Normally, the mutual information or spectral efficiency is chosen as a major performance index to select the service architecture for unicast services. A relay mode selection algorithm was presented based on the derived mutual information (Laneman *et al.*, 2004). A power-weighting model was proposed to mimic the asynchronous received signals of an MS for an OFDMA system with a given CP value (Adinoyi *et al.*, 2008). The power-weighting values can then be used to calculate the signal-to-noise-ratio (SINR) of the constructive and destructive signals received by the MS. The rest of the paper is organized as follows. The system model and the analytical formula are given in Sec. 2. Section 3 summarizes the simulation results. The conclusion is drawn in Sec. 4.

2. System Model

This paper considers a relay-enabled cellular network with M cells with radius R per cell is considered herein. Each cell is served by one BS and J transparent RSs (Yang *et al.*, 2009). The J RSs connect to their serving BS through the wireless backhaul links provided by the BS. The transmission of BS-to-RS link (also referred as relay link) and RS-to-MS link (also known as access link) are time-division multiplexed in a frame (Loa *et al.*, 2010). That is, a decode-and-forward relay technology is adopted here. In this network, each cell can be operated in one of the following four service architectures: SC-PTM, R-SC-PTM, SFN, and R-SFN. It is assumed that the ith BS $(1 \le i \le M)$ may perform MBMS counting procedure (Lee *et al.*, 2010) to obtain the number of MSs in the ith cell, N_i, during service initialization. An access service network gateway (ASN-GW) is responsible for selecting the best service architecture for the network based on the given N_i.

In the following, the mutual information and the spectral efficiency of each service architecture is derived. In SC-PTM, dynamic MCS can be adopted to enhance the spectral efficiency based on the channel quality feedback sent from MSs. Normally, the MCS is adjusted based on the MS with the worst signal quality in a cell (Lee *et al.*, 2010). Therefore, the mutual information and spectral efficiency of SC-PTM and R-SC-PTM are derived based on the distance between the BS and the farthest MS in the cell. Note that the location of the farthest MS depends on the number of MS in the cell. Different to SC-PTM, the dynamic MCS cannot be applied in SFN since the channel condition may be changed during the signaling exchanged between the ASN-GW and the BSs. However, the cell edge MSs may receive the signals transmitted from the other BSs belonging to the same SFN and thus, achieve the macro diversity gain. Hence, the mutual information and spectral efficiency of SFN and R-SFN is derived based on the MS located at the cell edge.

2.1 Average Mutual Information

Let ϕ_{-i}={1, 2,..., i-1, i+1, M} be the set of BSs except the ith BS. Consider a target MS located within the ith cell, the signal-to-interference plus noise ratio (SINR) of the target MS in SC-PTM is computed as $SINR_{SC-PTM} = P_i \left|a_i\right|^2 / \left(\sum_{m \in \varphi_{-i}} P_m \left|a_m\right|^2 + N_0 \right)$, where P_i is the transmission power of the ith BS; $\left|a_i\right|^2$ is the channel gain from the ith BS to a target MS; and N_0 is the power of the background noise (Laneman *et al.*, 2004). Assume that the channel gain depends only on the path-loss (Tang *et al.*, 2007), $SINR_{SC-PTM}$ can be rewritten as

$$SINR_{SC-PTM} = \frac{P_i d_i^{-\alpha}}{\sum_{m \in \varphi_{-i}} P_m d_i^{-\alpha} + N_0}, \qquad (1)$$

where α is the path loss exponent and d_i is a random variable denoting the distance between the target MS and the ith BS. The mutual information of SC-PTM, denoted as $I_{SC\text{-}PTM}$, is given by

$$I_{SC-PTM} = \log_2(1+SINR_{SC-PTM}) \text{ (bps/Hz)}. \quad (2)$$

Note that the performance of MBMS is bounded by the MS which is the farthest from the BS in the cell. Hence, the target MS is chosen as the farthest MS in the ith cell in SC-PTM.

In SFN, the MBMS signals transmitted from BSs belonging to the same SFN can be combined at the MS. In OFDMA, the constructive signal of SINR resulted from the asynchronous received signals at the MS can be modeled by the power weighting values (Adinoyi *et al.*, 2008). Let ω_i and (1- ω_i) be the power weighting values of the constructive signal and the destructive signal originated from the ith BS, respectively. The power weighting value can be obtained from (Adinoyi *et al.*, 2008) and is given by

$$\omega_i(\tau) = \begin{cases} 1, & 0 \le \tau \le T_{CP}, \\ 1 - \dfrac{\tau - T_{CP}}{T_u}, & T_{CP} \le \tau \le T_{CP} + T_u, \\ 0, & \text{otherwise}, \end{cases} \quad (3)$$

where τ is the delay time from the ith BS to the target MS; T_u is the length of the useful signal; and T_{CP} is the length of the cyclic prefix.

For a target MS located within the ith cell, the SINR of the target MS in SFN is given by

$$SINR_{SFN} = \frac{\sum_{i\in\varpi} P_i d_i^{-\alpha}\omega_i}{\sum_{k\in\varpi} P_k d_k^{-\alpha}(1-\omega_i) + \sum_{m\notin\varpi} P_m d_m^{-\alpha}\omega_m + N_0}, \quad (4)$$

where ϖ is the set of BSs formed a SFN and the size of the SFN is K (i.e., $|\varpi| = K$). The mutual information of SFN, denoted as I_{SFN}, can be derived as

$$I_{SFN} = \log_2(1+SINR_{SFN}) \text{ (bps/Hz)}. \quad (5)$$

Note that the performance of MBMS in SFN is bounded by the MS located at the border of SFN. Hence, the target MS in SFN is chosen from the MSs locating at the edge of the SFN which has the worse signal quality. As mentioned, decode-and-forward relay technology is considered in this paper. In decode-and-forward relay networks, the BS first transmits the MBMS content through the relay link and then re-transmits the same MBMS content together with all of its subordinate J RSs (i.e., the transmission time is doubled). Therefore, the target MS may achieve the cooperative diversity gain. Let $\phi_{-i}=\{1, 2, ..., i\text{-}1, i\text{+}1, M\}$ be the set of RSs serving by the ith BS. Consider a target MS located within the ith cell, the SINR of the target MS in R-SC-PTM is computed as

$$SINR_{R-SC-PTM} = \min\left(\sum_{j\in\psi_i} \frac{\sum_{i\in\varpi} P_i d_{i,Rij}^{-\alpha}}{\sum_{m\in\varphi_{-i}} P_m d_m^{-\alpha} + N_0}, \frac{P_i d_i^{-\alpha} + \sum_{j\in\psi_i} P_{Rij} d_{i,Rij}^{-\alpha}}{\sum_{m\in\varphi_{-i}} P_m d_m^{-\alpha} + \sum_{j\in\psi_i} P_{Rij} d_{i,Rij}^{-\alpha} + N_0}\right), \quad (6)$$

where $d_{m,Rij}$ is a random variable denoting the distance between the mth BS and the jth RS in the ith cell;

P_{Rij} is the transmission power of the jth RS in the ith cell; d_{Rij} is a random variable denoting the distance between the jth RS in the ith cell and the target MS. The mutual information of R-SC-PTM, denoted as $I_{R\text{-}SC\text{-}PTM}$, can be derived from the mutual information of the relay link and the access link (Laneman *et al.*, 2004). It gives

$$I_{R-SC-PTM} = \log_2(1 + SINR_{R-SC-PTM}) \text{ (bps/Hz)}. \tag{7}$$

Similar to SC-PTM, the target MS is chosen as the farthest MS in the ith cell in R-SFN, $SINR_{R\text{-}SFN}$, is computed as

$$SINR_{R-SFN} = \min\left(\sum_{i\in\varpi}\sum_{j\in\psi_i}\frac{\sum_{i\in\varpi} P_i d_{i,Rij}^{-\alpha}}{\sum_{m\notin\varpi} P_m d_{m,Rij}^{-\alpha} + N_0}, \frac{\sum_{i\in\varpi}\left(P_i d_i^{-\alpha}\omega_i + \sum_{j\in\psi_i} P_{Rij} d_{Rij}^{-\alpha}\omega_{ij}\right)}{\sum_{k\in\varpi}\left(P_k d_k^{-\alpha}(1-\omega_k) + \sum_{j\in\psi_k} P_{Rkj} d_{Rkj}^{-\alpha}(1-\omega_{kj})\right) + \sum_{m\notin\varpi} P_m d_m^{-\alpha} + \sum_{j\in\psi_m} P_{Rim} d_{Rim}^{-\alpha}\omega_{im} + N_0}\right), \tag{8}$$

where ω_{ij} is the power weighting value of the constructive signal originated from the jth RS in the ith cell. The mutual information of R-SFN, denoted as $I_{R\text{-}SFN}$, is derived as

$$I_{R-SFN} = \log_2(1 + SINR_{R-SFN}) \text{ (bps/Hz)}. \tag{9}$$

Similar to SFN, the target MS is chosen from the MS locating at the edge of the SFN which has the worse signal quality.

In MBMS, the spectral efficiency is normally measured over a given target coverage ratio x $(0 \le x \le 1)$. For example, 95% of the coverage area with a target packet error rate of 1% is chosen as a performance metric in (Srinivasab *et al.*, 2009). In (2), (5), (7), and (9), the mutual information for the farthest MS in the ith cell with known distance r to a BS or an RS is derived. The average mutual information can then be derived based on the target coverage ratio and the distribution of MSs. Consider the MSs are uniformly distributed in each cell (i.e., the total number of MSs in each cell may not be equal). For a given target coverage ratio x (e.g., x= 0.95), the probability that 'the distance between the farthest MS in a cell i containing N_i MSs to the ith BS is r' can be obtained based on two scenarios illustrated in Figs. 1(a) and 1(b), respectively. In the first scenario, part (or all) of the MSs are located within the target coverage area with ratio x (i.e., the circle with radius $\sqrt{x}R$ in Fig. 1(a)). The probability that 'the distance between the farthest MS located within the coverage ratio x in a cell i containing N_i MSs and the ith BS is r' is given by

$$p(r, N_i, x) = 2N_i r \frac{((1-x)R^2 + r^2)^{N_i - 1}}{R^{2N_i}},\ r \in (0, \sqrt{x}R). \tag{10}$$

For x= 1 (i.e., 100% coverage), (10) can be rewritten as

$$p(r, N_i, 1) = 2N_i \frac{r^{2N_i - 1}}{R^{2N_i}},\ r \in (0, R). \tag{11}$$

In the second scenario, no MSs are located within the target coverage area. In this scenario, the distance between the farthest MS located within the target coverage area to its serving BS is set to be the boundary of the target coverage area (i.e., the circle with radius xR in Fig. 1(b)). The probability of the second scenario, denoted as $p(N_i,x)$, is given by

$$p(N_i, x) = (1-x)^{N_i}. \tag{12}$$

Hence, the average mutual information of SC-PTM, $\overline{I}_{SC-PTM}$, can be derived from the mutual information obtained in (2) by setting $d_i = r$ and $\sqrt{x}R$ in the first and the second scenarios, respectively. It gives

$$\overline{I}_{SC-PTM} = \int_{r=0}^{\sqrt{x}R} \log_2\left(1+\frac{P_i r^{-\alpha}}{\sum_{m\in\varphi_{-1}} P_m d_{m,r}^{-\alpha}+N_0}\right)p(r,N_i,x)dr + \log_2\left(1+\frac{P_i(\sqrt{x}R)^{-\alpha}}{\sum_{m\in\varphi_{-1}} P_m d_{m,\sqrt{x}R}^{-\alpha}+N_0}\right)p(N_i,x), \qquad (13)$$

where $d_{m,r}$ is the distance between the mth BS and the target MS whose distance to the ith BS is r; $d_{m,\sqrt{x}R}$ is the distance between the mth BS and the target MS whose distance to the ith BS is $\sqrt{x}R$.
Similarly, the average mutual information of R-SC-PTM, $\overline{I}_{R-SC-PTM}$, is

$$\overline{I}_{R-SC-PTM} = \frac{1}{2}\min(\log_2\left(1+\sum_{j\in\psi_i}\frac{P_i d_{i,Rij}^{-\alpha}}{\sum_{m\in\varphi_{-1}} P_m d_{m,Rij}^{-\alpha}+N_0}\right), \int_{r=0}^{\sqrt{x}R}\log_2\left(1+\frac{P_i r^{-\alpha}+\sum_{j\in\psi_i}P_{Rij}d_{Rij,r}^{-\alpha}}{\sum_{m\in\varphi_{-1}}\left(P_m d_{m,r}^{-\alpha}+\sum_{j\in\psi_i}P_{Rmj}d_{Rmj,r}^{-\alpha}\right)+N_0}\right)p(r,N_i,x)dr$$
$$+\log_2\left(1+\frac{P_i(\sqrt{x}R)^{-\alpha}+\sum_{j\in\psi_i}P_{Rij}d_{Rij,\sqrt{x}R}^{-\alpha}}{\sum_{m\in\varphi_{-1}}\left(P_m d_{m,\sqrt{x}R}^{-\alpha}+\sum_{j\in\psi_m}P_{Rmj}d_{Rmj,\sqrt{x}R}^{-\alpha}\right)+N_0}\right)p(N_i,x)), \qquad (14)$$

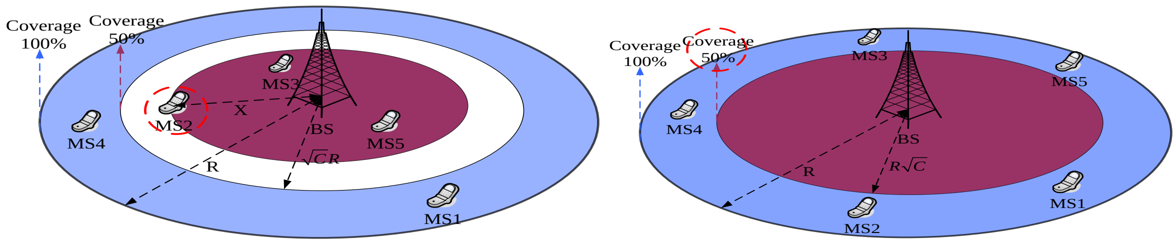
where $d_{Rij,r}$ is the distance between the jth RS in cell i and the target MS whose distance to the jth RS in cell i is r; $d_{Rij,\sqrt{x}R}$ is the distance between the jth RS in cell i and the target MS whose distance to the jth RS in cell i is $\sqrt{x}R$. In SFN and R-SFN, the coverage edge depends only on the coverage ratio and is independent of users' distribution. The average mutual information of $\overline{I}_{SFN}$ and $\overline{I}_{R-SFN}$ can be obtained by adjusting the location of the target MS from R to $\sqrt{x}R$. Hence, we have

$$\overline{I}_{SFN} = \log_2\left(1+\frac{\sum_{i\in\varpi}P_i d_{i,\sqrt{x}R}^{-\alpha}\omega_i}{\sum_{m\in\varpi}P_m d_{m,\sqrt{x}R}^{-\alpha}(1-\omega_m)+\sum_{n\notin\varpi}P_n d_{n,\sqrt{x}R}^{-\alpha}+N_0}\right) \qquad (15)$$

and

$$\bar{I}_{R-SFN} = \frac{1}{2}\min(\log_2\left(1+\sum_{i\in\varpi}\sum_{j\in\psi_i}\frac{P_i d_{i,Rij}^{-\alpha}}{\sum_{m\in\varphi_{-1}} P_m d_{m,Rij}^{-\alpha}+N_0}\right), \tag{16}$$

$$\log_2\left(1+\frac{\sum_{i\in\varpi}\left(P_i d_{i,\sqrt{x}R}^{-\alpha}\omega_i+\sum_{j\in\psi_i}P_{Rij}d_{Rij,\sqrt{x}R}^{-\alpha}\omega_{ij}\right)}{\sum_{i\in\varpi}\left(P_i d_{i,\sqrt{x}R}^{-\alpha}(1-\omega_i)+\sum_{j\in\psi_i}P_{Rij}d_{Rij,\sqrt{x}R}^{-\alpha}(1-\omega_{ij})\right)+\sum_{m\notin\varpi}\left(P_m d_{m,\sqrt{x}R}^{-\alpha}+\sum_{j\in\psi_m}P_{Rmj}d_{Rmj,\sqrt{x}R}^{-\alpha}\right)+N_0}\right)).$$



(a) Part of (or all) users inside coverage (b) No user inside coverage

Figure 1. Users are located within the target coverage area

2.2 Average Spectral Efficiency

The spectral efficiency is the major performance index for MBMS and is given by

$$\bar{S}_y = \frac{DATA_{bits/symbol}(SINR_y)\times N_{symbol/DL-subframe}}{T_{DL-subframe}\times BW}\ \text{(bps/Hz)}, \tag{17}$$

where $DATA_{bits/symbol}$ is the number of bits carried in an OFDMA symbol and is a function of $SINR_y$. $SINR_y$ is the $SINR$ of the target MS using service architecture $y \in A$, where A = {SC-PTM, SFN, R-SC-PTM, R-SFN} is the set of service architectures; $N_{symbol/DL-subframe}$ is the number of symbols carried by a downlink sub-frame; $T_{DL-subframe}$ is the time required to transmit a downlink sub-frame; and BW is the overall bandwidth. $DATA_{bits/symbol}$ can be derived from the SINR of the cell edge MS in service architecture y, $SINR_y$, that can attain the highest MCS level. The value of $DATA_{bits/symbol}$ for different MCS levels is illustrated in Table I. In this example, the SINR threshold, T_{SINR}, is determined from the target bit error rate (BER) of 10^{-3}.

3. Simulation Results

Simulations were conducted on a C++ platform to verify the accuracy of the analysis. In the simulations, a total of 19 cells were investigated (M =19);each cell has three RSs (J = 3); the inter-site distance (ISD) of 1.5 km was considered (Srinivasab *et al.*, 2009, Hamiti *et al.*, 2009, 3GPP R2-060955, 2006).,which resulted in a cell radius of 866 m(R);the distance between BS and RS was set to be R/2; the number of MSs in each cell (Ni) was set to be 5, 10, and 50, respectively. It was assumed that MSs were uniformly distributed in each cell and path-loss channel model was considered.

Figure 2 depicts the probability distribution function of the location of the farthest user in a cell. The simulation results were coincided with the analysis, which verify the accuracy of the analytical formula of (10). The farthest user has a higher probability to stay at the cell edge if there are more users in a cell. From (1) and (6), the SINR for SC-PTM and R-SC-PTM decreases if the farthest user has a higher probability to stay at the cell edge. It may also result in a lower spectral efficiency according to (2) and (7).

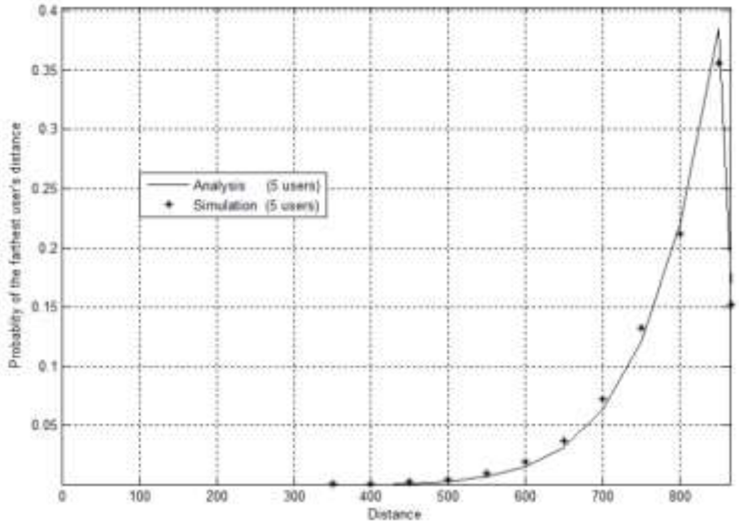


Fig. 2. Probability distribution function of the location of the farthest user in a cell

Figures 3 and 4 showed the analytical results of average mutual information and average spectral efficiency of SC-PTM, R-SC-PTM, SFN and R-SFN for different number of users for 95% coverage, respectively. In Fig. 3, the average mutual information for different service architectures were investigated. In this paper, the selection for the service architecture is based on average spectral efficiency instead of the mutual information since the latter one is the upper bound of spectral efficiency. The best service architecture is the one which maximizes the average spectral efficiency. Fig. 4 demonstrates that SC-PTM achieves the highest the spectral efficiency if the total number of MSs in a cell is less than six. In this case, the farthest user has a higher SINRSC-PTM because it has a lower probability stay at the cell edge. However, R-SFN becomes the best service architecture if the total number of MSs increases. It is also found in Fig. 4 that R-SFN can have a higher spectral efficiency if the distance between the BS and the RS is 0.5*R* or 0.7*R*. It is also found that the spectral efficiency for R-SC-PTM is worse than SC-PTM. The main reason is that SINRR-SC-PTM is smaller because the MS may receive extra interference generated by the RSs of the neighbor cells.

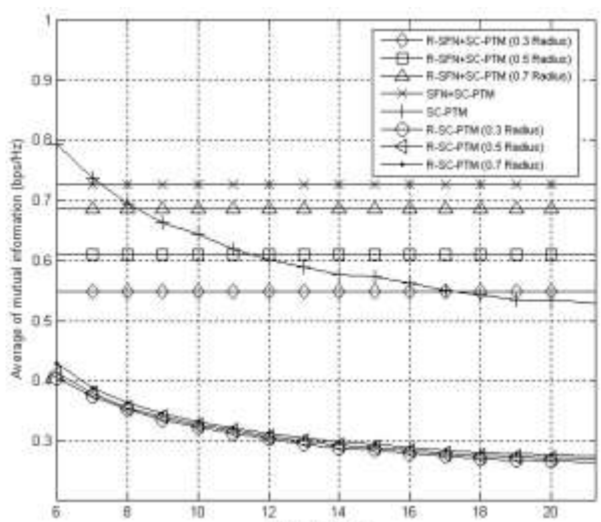


Fig. 3. Average mutual information for 95% coverage

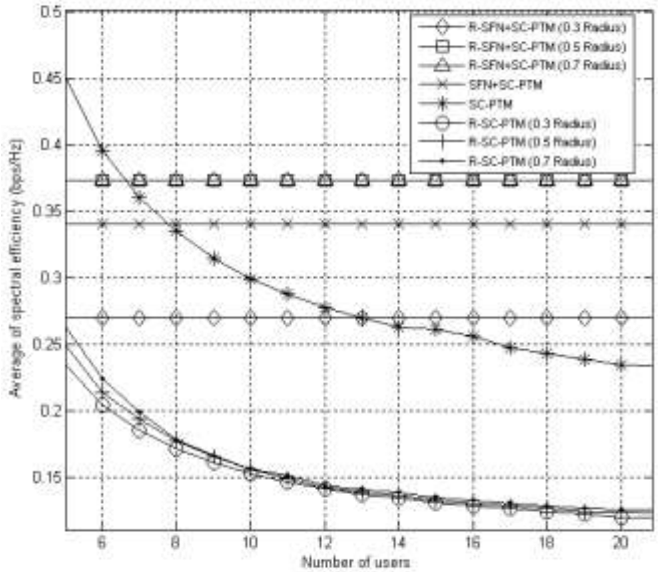


Fig. 4. Average spectral efficiency for 95% coverage.

4. Conclusion

This paper presents analytical models to calculate the mutual information and spectral efficiency of MBMS transmission for the different service architectures with a given target coverage ratio and different number of MSs in each cell. The derived mutual information and spectral efficiency can be used to select the best service architecture. The accuracy of the analysis is verified via computer simulation. It is suggested that the BS uses SC-PTM if the total number of MSs in a cell is not greater than six and chooses R-SFN if there are more MSs in the cell.

Acknowledgements

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