User-Bin Allocation Methods for Adaptive-OFDM Downlinks of Mobile Transmissions

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Questions to be addressed:

- DOWNLINK TRANSMISSION SCHEMES
- CHANNEL MODEL
- USER-BIN ALLOCATION BY FREQUENCY-HOPPING
- OPTIMAL ALLOCATION OF THE USER-BIN
- COMPARISON BETWEEN THE BIN-ALLOCATION METHODS
- EVALUATION OF THE UPLINK SIGNALLING BIT-RATE REQUIRED BY THE ALLOCATION METHODS
- CONCLUSIONS

User-Bin Definition

The user frequency-bandwidth:

- a fixed number of sub-carriers C_u, out of the N_u useful sub-carriers of the OFDM scheme, along a fixed number of T_u OFDM symbol periods, generating the user-bin of $S_T = C_u \times T_u$ QAM symbols.
- The available bandwidth, i.e. N_u sub-carriers, is split into $B_u = N_u/C_u$ bins allocated to different users

User-Bin Allocation Methods

User-bin allocation methods ensure the frequency diversity, to compensate the variable attenuation of the Rayleigh fade of the mobile multipath channel:

- Frequency hoping FH - the frequency position of a user-bin is allocated according to a FH
  - The hopping frequency equals the user-bin rate; this method is employed in [1].
- Optimal Allocation (OpAl) - each user-bin is allocated the best frequency position,
  - the group of C_u sub-carriers that ensure the best average SINR for the bin-period envisaged;
  - involves the state-prediction of all available bins, over a prediction time-horizon, performed by the user mobile station.

User-Bin Allocation Methods

The bin-allocation method affects:

- The throughput provided by the downlink connection
- The signaling traffic both on the downlink and the uplink connections
- The time-horizon of the channel-state prediction
- The computational load of the mobile station and of the scheduler within the base station

Downlink transmission scheme

OFDM – based downlink scheme with the following parameters:

- OFDM-symbol frequency f_s = 10 kHz, guard interval G = 11 µs, leading to a payload OFDM-symbol rate f_s’ = 9.09 kHz;
- N_u = 1000 payload sub-carriers, carrier frequency f_c = 1.9 GHz; number of user-bins available is B_u = 50.
- The user-bin dimensions are S_T = 20 sc x 6 symbol periods with a effective bin-rate D_{bin} = 1501 bins/s;
- There are S_T = 120 QAM-symbols/bin out of which only S_u = 108 would be payload symbols.
- The OFDM employs adaptively one of the two families of non-coded or LDPC-coded QAM constellations (Ti - thresholds)

Adaptive Non-Coded Configuration – ANCC

– ANCC; F = 8 non-coded constellations

(Const. No.); n_l(bits/symb)	(1); 1	(2); 2	(3); 3	(4); 4	(5); 5	(6); 6	(7); 7	(8); 8
T_l [dB]	-2	8.3	13.2	16.2	20.2	23.6	26.6	29.8
D_{nl} [kbit/s]	162	324	486	648	810	972	1134	1285

Table 1 Parameters n_l, T_l, and Dnl of the adaptive non-coded QAM set of configurations, ANCC

-the nominal bit rate of ANCC D_{nl} is computed by (1.a):

$$D_{nl} = D_{bin} \cdot S_u \cdot n_l \cdot \left(1 - \frac{t}{S_u \cdot n_l}\right); \qquad (1.a)$$

Adaptive LDPC-Coded Configuration - ACC

- ACC; contains a set of F = 16 coded constellations

(Const. No.); n_i; n_{ci}	(1); 1;1	(2); 1; 1	(3); 2; 2	(4); 2;2	(5); 2; 1	(6); 3; 2	(7); 3; 2	(8); 4; 2
R_{cfgi}	0,29	0.49	0.47	0.68	0.85	0.65	0.79	0.73
T_i [dB]	-2	-1	2.5	4.5	6.5	8	9	11
D_{ci} [kbit/s]	47	80	152	221	275	314	383	476
(Const. No.); n_i; n_{ci}	(9); 4; 2	(10); 5; 2	(11); 5; 2	(11); 6; 4	(12); 7; 2	(14); 8; 4	(15); 8; 4	(16); 8; 0
R_{cfgi}	0.84	0.79	0.87	0.86	0.85	0.82	0.90	1
T_i [dB]	13	15	16.5	18.5	21	23.5	25	30
D_{ci} [kbit/s]	545	638	707	883	962	1064	1112	1285

Table 2 Parameters n_I, T_I, D_{cI} and R_{cfgI} of the adaptive coded QAM set of configurations, ACC

- The LDPC codes are array-based L(2,q) codes

Adaptive LDPC-Coded Configuration - ACC

-The nominal bit rate of ACC D_{ncl} is computed by (1.b):

$$D_{ncl} = D_{bin} \cdot M_u \cdot n_l \cdot R_{cfgl}; \qquad (1.b)$$

- The throughput Θ_l provided by a QAM modulation is computed using (2):

$$\Theta_l(SNR) = D_{nl}(1 - BinErl(SINR)); \qquad (2)$$

- The bin error rate of a non-coded scheme is computed, by (3), [2],

$$BinErrl(SINR) = 1 - (1 - p_{eNl}(SINR))^{N_u}; \qquad (3)$$

-The bin error rates of the coded configurations, B_{inErr_l}, and their throughput vs. SINR curves were determined by computer simulations, using simulation programs [5].

Throughput vs. SINR of ANCC and ACC

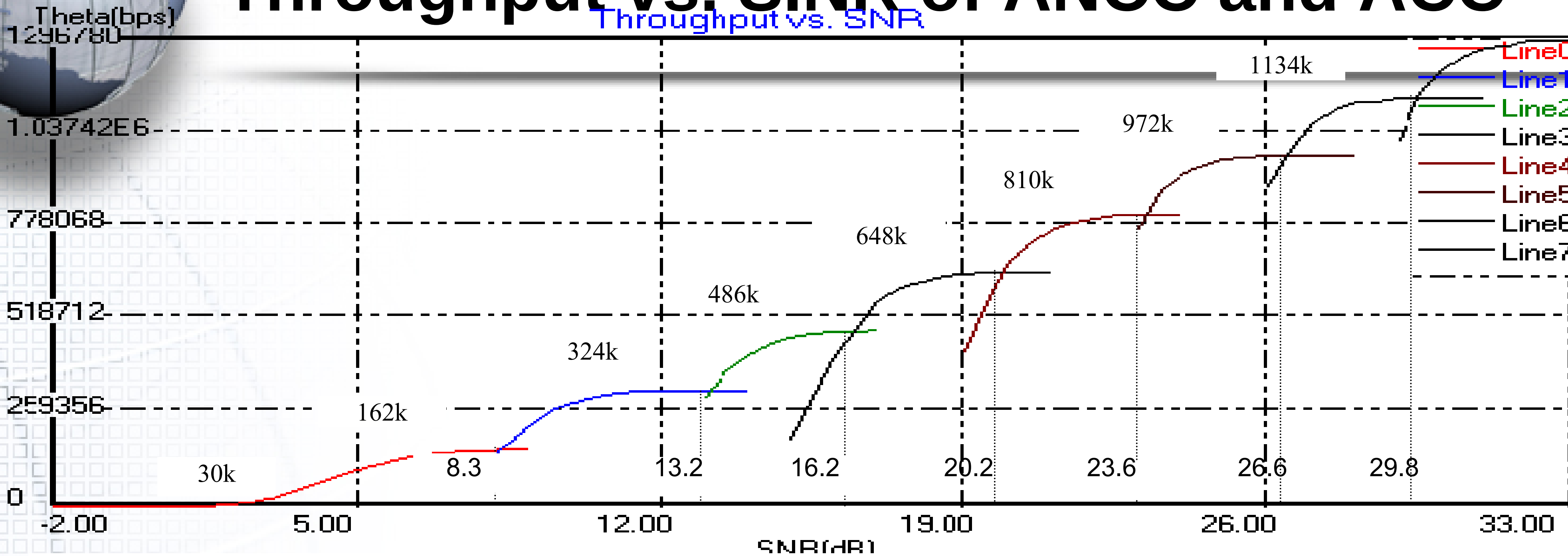


Figure 1 Θ vs. SINR of the ANCC set on a flat AWGN channel

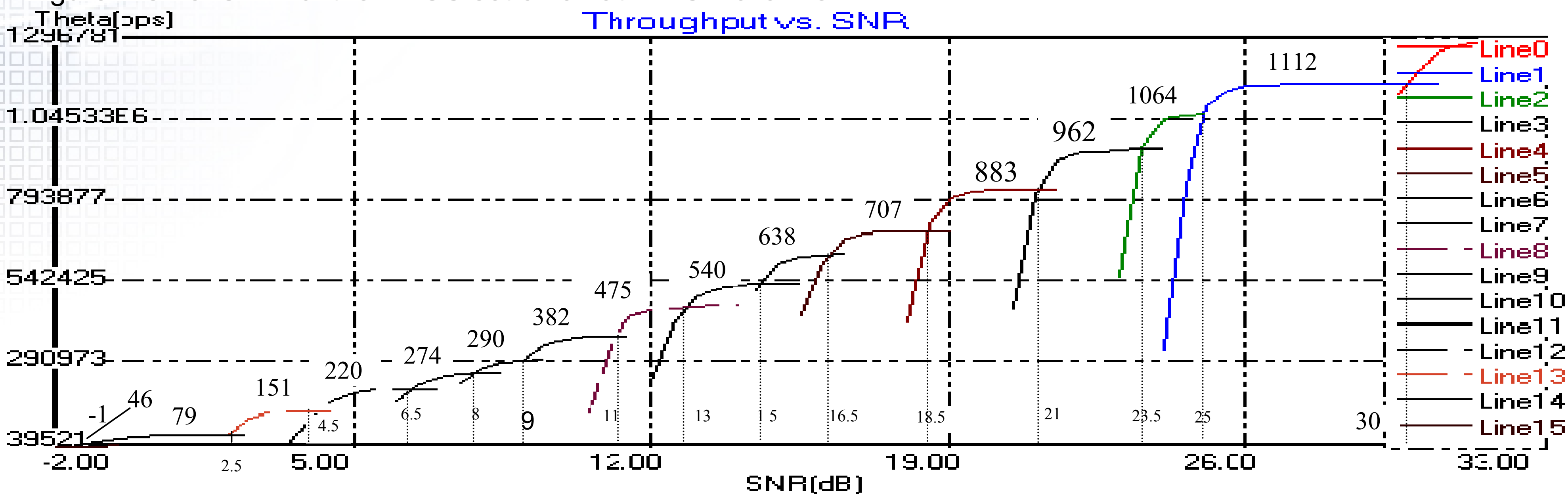
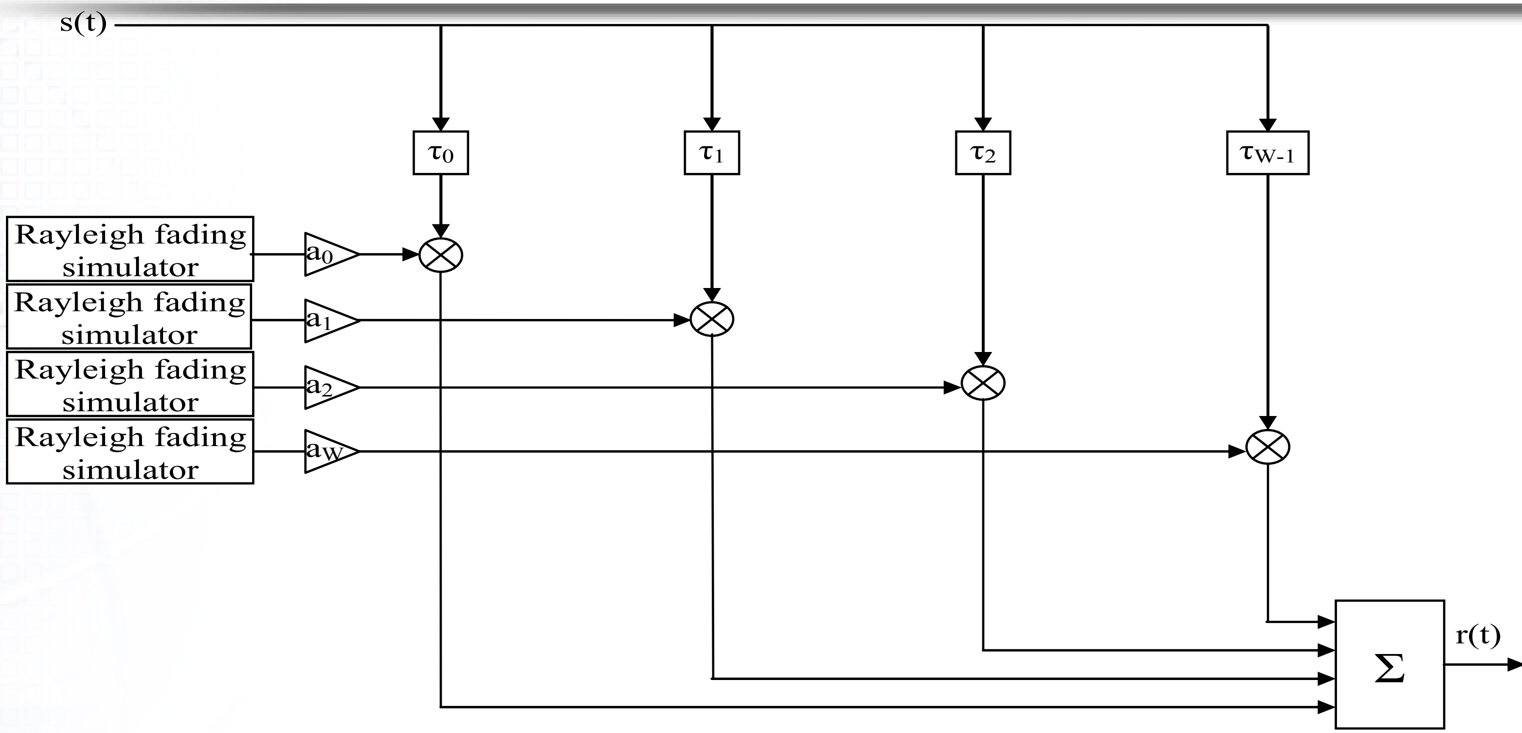


Figure 2. Θ vs. SINR of ACC set on a flat AWGN channel

CHANNEL MODEL



- The multipath Rayleigh (MPR) channel model CH assumes W = 4 Rayleigh-faded paths.
- The average power of the first arrived wave is considered for the implementation of a given SINR value.
- The relative attenuations and delays are respectively: 0, 3, 6, 9 dB and 0, 200, 400 and 600 ns.
- The user speed v_{user} = 120 km/h, dictates the coherence time $T_C = 0.423/f_D$;
  - f_D – the Doppler shift computed for the carrier frequency f_c

DISTRIBUTION OF THE RATED-LEVEL OF THE RECEIVED FADED SIGNAL

-The p.d.f. of i-th Rayleigh-faded wave, employed to compute the p.d.f. of the rated level $x = r/\sigma$:

$$p_i\left(\frac{r}{\sigma}\right) = \frac{r/\sigma}{A_i^2/\sigma^2} \exp\left(-\frac{r^2/\sigma^2}{2A_i^2/\sigma^2}\right) \qquad (4)$$

- For a signal composed of W Rayleigh-faded waves with relative attenuations a_i, and delays τ_i, the p.d.f. of rated level of the received signal transmitted on the k-th subcarrier should be computed taking into account the phase differences Ω_{kij} between two waves, i and j:

$$\Omega k_{ij} = 2\pi f_k \left(\tau_i - \tau_j\right) \qquad (5)$$

DISTRIBUTION OF THE RATED-LEVEL OF THE RECEIVED FADED SIGNAL

- p.d.f. of the rated level *r/σ* denoted by *r* is computed by:

$$P_k(r)=\int_0^\infty p_1(x_1)\int_0^\infty p_2(x_2)\cdots\int_0^\infty p_{W-1}(x_{W-1})\cdot U\left(x_1,x_2,\ldots x_{W-1},\Omega k_{1W},\Omega k_{2W},\ldots,\Omega k_{(W-1)W}\right)dx_{W-1}\ldots dx_2 dx_1 \quad (6)$$

where:

$$U\left(x_1,x_2,\ldots x_{W-1},\Omega k_{1W},\Omega k_{2W},\ldots,\Omega k_{(W-1)W}\right)=\begin{cases}0; \quad \text{if} \quad r^2-\left(\sum_{i=1}^{W-1}x_i\sin\Omega k_{iW}\right)^2<0;\\ p_W\left(-\sum_{i=1}^{W-1}x_i\cos\Omega k_{iW}+\sqrt{r^2-\left(\sum_{i=1}^{W-1}x_i\sin\Omega k_{iW}\right)^2}\right);\text{otherwise}\end{cases} \quad (7)$$

– $p_l(x_l)$ – probability of the level received on path l to have the value x_l
– U – probability of the level on the last path to take a value so that, given the other w-1 level and delays, the composed level equals r

USER-BIN ALLOCATION BY FREQUENCY-HOPPING

Characteristics:

- The B_u available bins are allocated to each user according to a B_u-states pseudo-random sequence,
- The FH sequence is generated according to the linear congruential method [7].
- The hopping frequency is the reciprocal of the bin duration
- Each user enters into the pseudo-random sequence with a different initial value, delivered by the base station at signing-in.
- The mobile station performs a prediction of the channel state across the time-horizon greater than the time response of the adaptation scheme, only for the frequency bin it will use next; the time horizon is min. 3 bin periods.
- It then sends to the base station only the index of the configuration (code + QAM) it should employ, from the stored set (ANCC or ACC).

Probability to Employ Configuration l

– The probability of the rated level to lie between a pair of threshold T_l and T_{l+1}(dB) where configuration l should be use:
  - For the SINR threshold T_l of the QAM transmission, the rated level threshold J_l is:

$$J_l = \frac{A_l}{\sigma_l} = 10^{T_l / 20}$$

– The probability of the rated level, on subcarrier k, to lie between thresholds J_l, J_{l+1} is obtained by integrating $P_k(r)$ (6) between them.

– The selection of the employed modulation *l* is made according to the average of the rated levels received on the C_u subcarriers of that bin.

– For FH bin-allocation method, the probability of a bin to be assigned to one user is $1/B_u$.

Probability to Employ Configuration l

– The probability of a user to employ the configuration l is obtained by averaging, over all N_u subcarriers, the probability of the rated level of the signal, received on a subcarrier k, to lie between thresholds, J_l, J_{l+1}:

$$P_{FH}\left(J_l < r < J_{l+1}\right) = \sum_{k=1}^{N_u} \frac{1}{N_u} \int_{J_l}^{J_{l+1}} P_k(x)\,dx \qquad (9)$$

In this case $U\left(x_1, x_2, \ldots x_{W-1}, \Omega k_{1W}, \Omega k_{2W}, \ldots, \Omega k_{(W-1)W}\right)$ from (6) becomes:

$$U_{FH}\left(x_1, x_2, \ldots x_{W-1}, \Omega k_{1W}, \Omega k_{2W}, \ldots, \Omega k_{(C-1)W}\right) = \int_{U_0}^{U_1} p_W(x_W)\cdot y(x_W)\,dx_w$$

where $U_0 = -\sum_{i=1}^{W-1} x_i \cos\Omega k_{iW} + \sqrt{A_i^2 - \left(\sum_{i=1}^{W-1} x_i \sin\Omega k_{iW}\right)^2}$; $U_1 = -\sum_{i=1}^{W-1} x_i \cos\Omega k_{iW} + \sqrt{A_{i+1}^2 - \left(\sum_{i=1}^{W-1} x_i \sin\Omega k_{iW}\right)^2}$

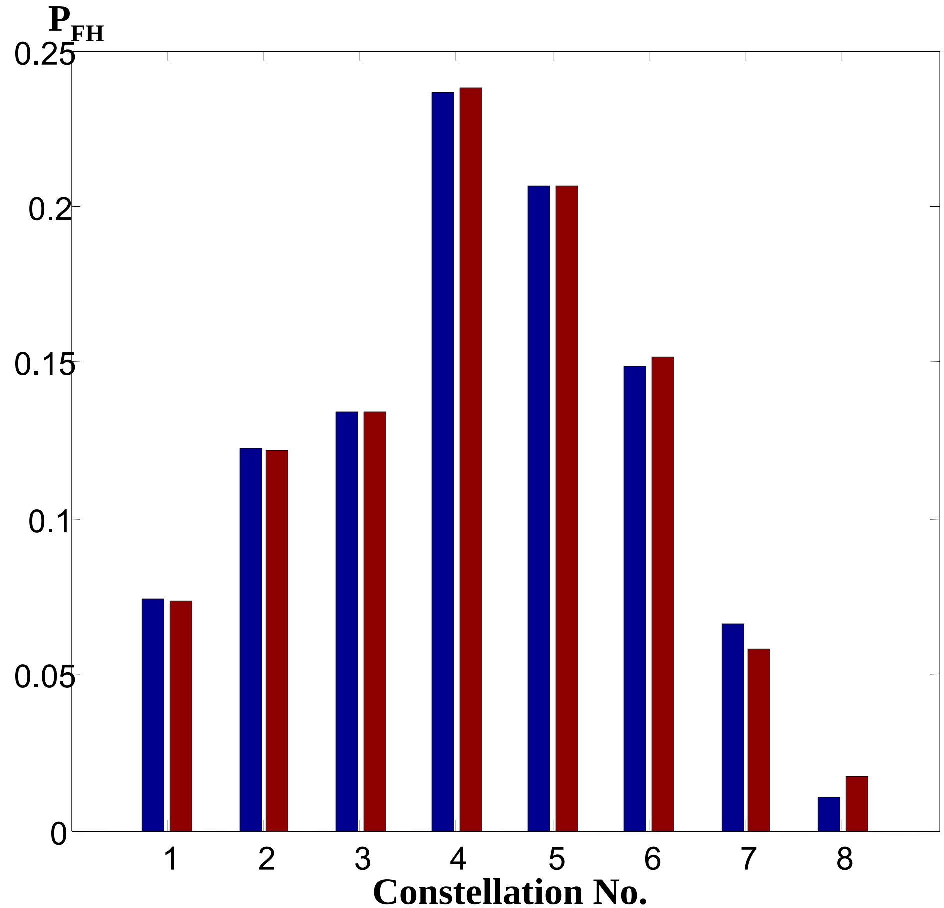
and $y(x_W) = \begin{cases} 1; & x_W \in R \\ 0; & x_W \notin R \end{cases}$

Probability to Employ Configuration I

– The probabilities of a user to employ a certain modulation were computed using (5) – (9), for the ANCC non-coded set on the Rayleigh-channel CH, for an SINR = 16 dB (blue bars);

– The same probabilities were evaluated by computer-simulation for 10,000 transmitted bins/user (red bars)

– The differences between the theoretical evaluation and the simulation results are small enough to consider the simulation reliable.



Const. No - ANCC	1	2	3	4	5	6	7	8
P_{FH} -computed	0.0745	0.1228	0.1341	0.2362	0.2066	0.1488	0.0663	0.0107
N_{FH}/10000 - simulated	0.0734	0.1215	0.1338	0.2381	0.2062	0.1515	0.0581	0.0174

OPTIMAL ALLOCATION OF THE USER-BIN

Characteristics:

- Allocates to each user the frequency bin that ensures the highest SINR and maximizes the average throughput of the whole carrier.
- The SINR evaluation is based on the channel prediction performed across a time-horizon greater than the time response of the adaptation scheme;
- Performs the prediction for all B_u (50) bins in the MS
- Sends the SINR values on min. 8 bits/value (depending of the prediction accuracy)
- Requires the confirmation from the BS
- The time-horizon is 5 bin periods.

Probability to Employ Configuration I

– The probability $P_{OA}(J_l, J_{l+1})$ that the maximum rated level lies between thresholds J_l, J_{l+1}, requires the computation of the probability of the average rated level of bin m to lie in this domain, P_{am}, multiplied with the probability that the average rated levels of all other bins, Q_{mj} to be smaller than the average rated level of bin m; is expressed by:

$$P_{OA}(J_l < r < J_{l+1}) = \sum_{m=1}^{B_u} \left(\int_{J_i}^{J_{l+1}} Pa_m(x_m) \cdot \prod_{\substack{j=1 \\ j \neq m}}^{B_u} Q_{mj}(x_m) dx_m \right) \qquad (10)$$

$$\text{where} \quad Pa_m(x) = \frac{1}{C_u} \sum_{q=1}^{C_u} P_{(mC_u+q)}(x); \text{and}\, Q_{mj}(x) = \begin{cases} 1 & \text{if} \quad Pa_j(x) < Pa_m(x) \\ 0 & \text{otherwise} \end{cases}$$

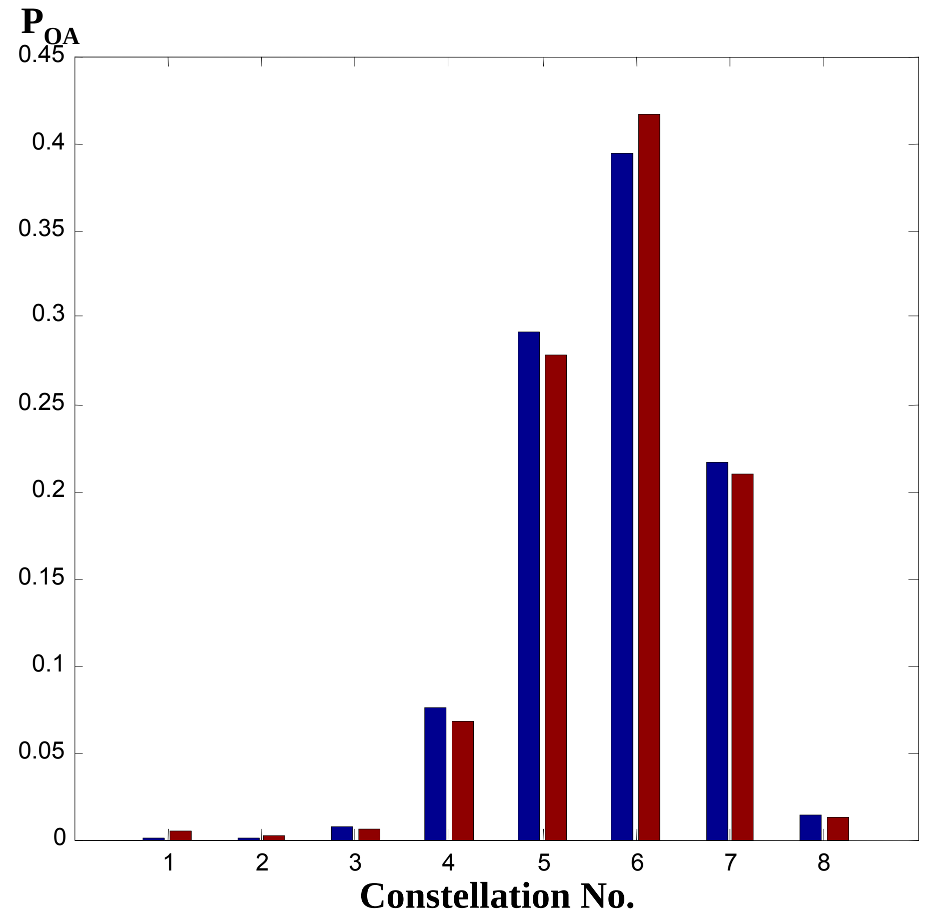
– $mC_U + q$ – the index of subcarrier q in bin m

Probability to Employ Configuration I

– The probabilities of a user to employ a certain modulation were computed using (6) – (10), for the ANCC non-coded set on the Rayleigh-channel CH, for an SINR = 16 dB;

– The same probabilities were evaluated by computer-simulation for 10,000 transmitted bins/user

– The differences between the theoretical evaluation and the simulation results are small enough (2%) to consider the simulation with an acceptable reliability.



Const. No - ANCC	1	2	3	4	5	6	7	8
P_{OA} –computed	0.0012	0.0013	0.0076	0.0756	0.2910	0.3936	0.2158	0.0139
N_{OA} /10000 - simulated	0.0050	0.0025	0.0065	0.0675	0.2785	0.4165	0.2105	0.0130

Table 4. Employment probabilities of the 8 constellations of ANCC for the OpAI allocation method – P_{OA} (SINR 16 dB)

Comparison between the bin-allocation methods:

- The OpAl method employs most often modulations 5, 6 and 7, though according to table 1 it should employ modulation 4; this is because, by taking the bin with the highest SINR available, it takes advantage of the frequency diversity of the multipath channel in the best way possible.
- This leads to an average of 5.76 transmitted bits/QAM symbol.
- The FH method employs in an more equally-distributed manner constellations 2 to 6 leading to an average number of bits/QAM symbol of only 4.15.
- This is because the generating pattern is independent from the channel behavior

THROUGHPUT PERFORMANCES OF THE PROPOSED USER-BIN ALLOCATION METHODS

– The throughput ensured by the set of ANCC or ACC employed in the OFDM scheme is influenced by:
  – the properties of the (non) coded modulation (no. of bits/symbol, configuration rate, BER vs. SINR performances)
  – the bin allocation method
– It should be computed by multiplying the probability P(l) of using a (non) coded modulation to the average throughput Θ_l (2) provided by that modulation between J_l, J_{l+1}.

$$\Theta_{av}(\mathrm{SINR}) = \sum_{l=1}^{F} P(l)\cdot\Theta_l; \quad P(l) = \begin{cases} P_{FH}(J_l, J_{l+1}) & \text{for Frequency Hopping} \\ P_{AO}(J_l, J_{l+1}) & \text{for Optimal Allocation} \end{cases} \quad (11)$$

Simulation Comparison OpAl vs. FH

– Both for the ANCC and LDPC-ACC,
– For SINR ranging from -2 to + 33 dB in 0.5 dB steps,
– Transmitting 500 bins/user for each SINR value.
– The user-bin occupies a frequency bandwidth of 200 kHz $\Rightarrow$ the spectral efficiency is computed

Simulation Comparison OpAl vs. FH

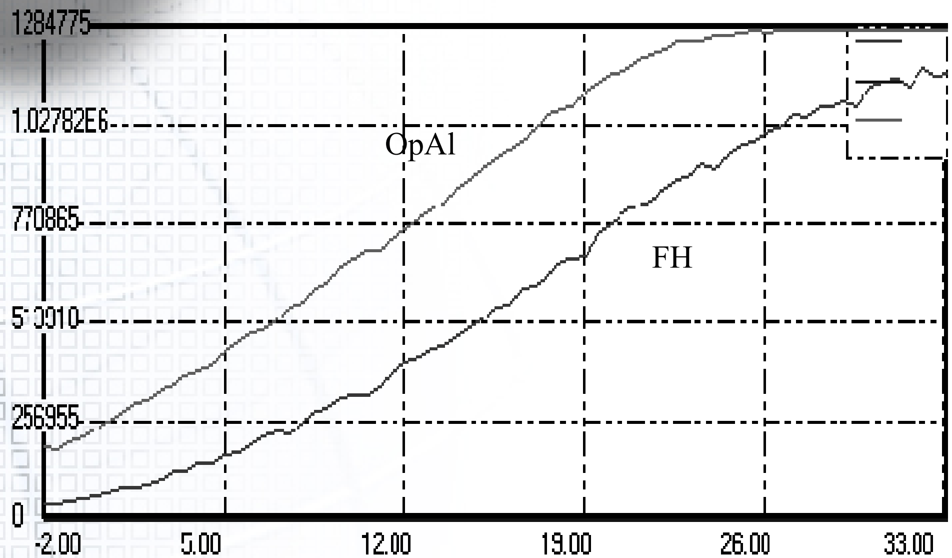


Figure 6 Θ_{avNC} vs. SINR of ANCC for FH and OpAl on CH

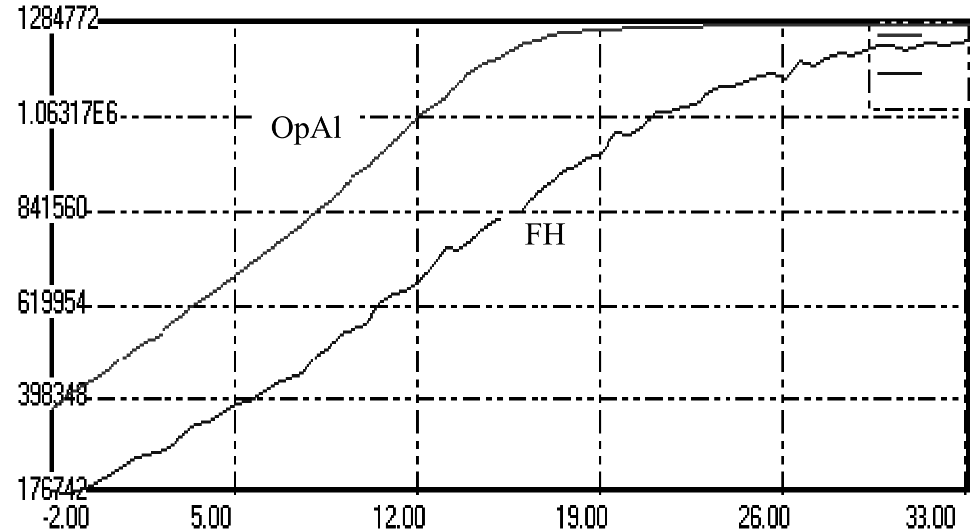


Figure 7 Θ_{avC} vs. SINR of ACC for FH and OpAl on CH

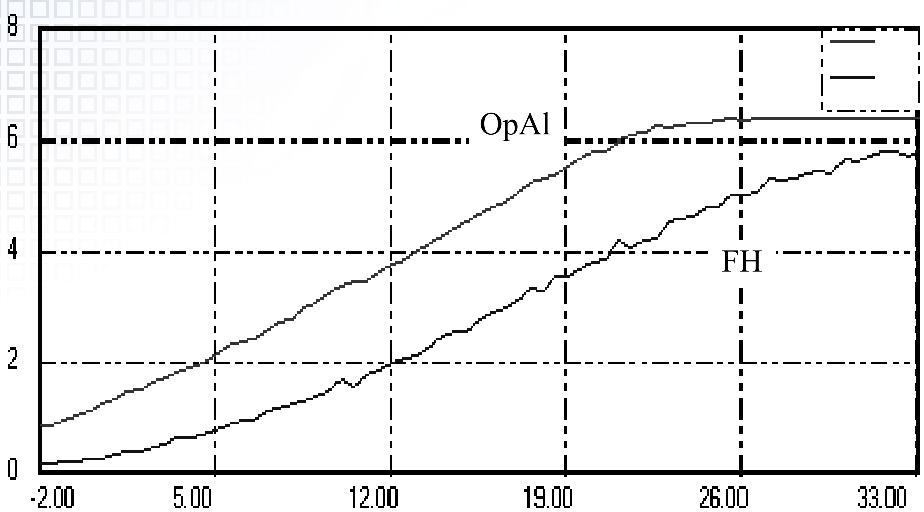


Figure 8 β_{NC} vs. SINR of ANCC for FH and OpAl on CH

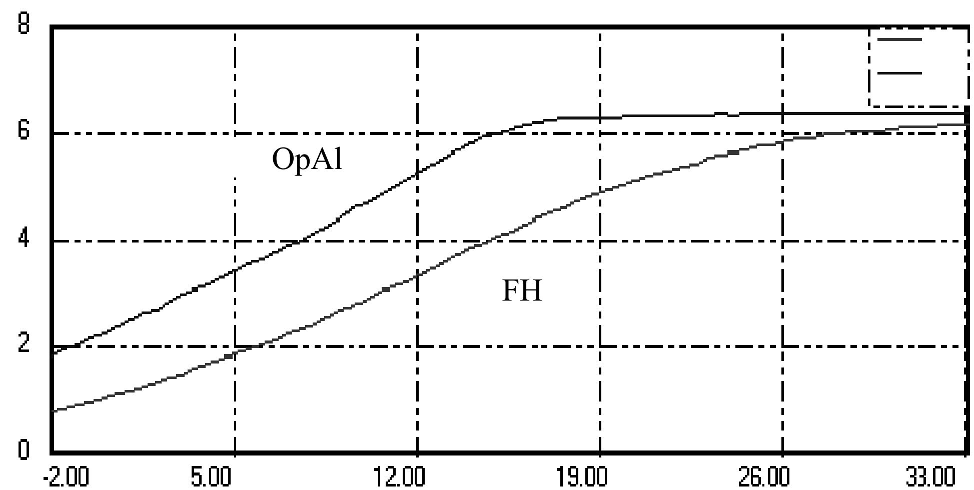


Figure 9 β_{avC} vs. SINR of ACC for FH and OpAl on CH

Simulation Comparison OpAl vs. FH

- Optimal Allocation method leads to significant increases of the spectral efficiency and throughput, compared to the values ensured by the Frequency Hopping allocation method.
- This increase, more significant at moderate SINR ratios, may reach values between 1 – 1.7 bps/Hz, both for the non-coded and coded sets of modulations.
- The performances of the coded ACC set of modulations that are allocated with the FH method (figure 9) are comparable to the performances ensured by the non-coded ANCC set of modulations that are allocated with the OpAl method (figure 8). Comparing the corresponding curves, the differences between the spectral efficiencies are smaller than 0.5 bps/Hz, in favor of the OpAl method.
- The ACC ensures higher spectral efficiencies than the ANCC at low and moderate SINRs, the difference raising to 1.2 bps/Hz

EVALUATION OF THE UPLINK SIGNALLING BIT-RATE REQUIRED BY THE ALLOCATION METHODS

– The FH method transmits on the uplink the index of the modulation to be employed in the bin that is to be transmitted after the prediction time-horizon.
– This index could be transmitted on maximum 4 bits, involving a signaling bit rate/user RSFH = 4 bits/bin x Dbin = 6.67 kbps, for the transmission scheme employed.
– The prediction time-horizon is 3-4 bin periods
– The computational load in the MS is small
– The computational load in the BS-scheduler is small

EVALUATION OF THE UPLINK SIGNALLING BIT-RATE REQUIRED BY THE ALLOCATION METHODS

- The OpAI transmits all the SINR values predicted for B_u (50) bins.
- These values require 8 bits each, for the SINR range considered, $\Rightarrow$ signaling bit-rate: $R_{SOA} = B_u \times 8 \times D_{bin}$ = 667 kbps/user - prohibitive.
- The prediction time-horizon is 5 bin periods – decreased accuracy
- The computational load in MS is significantly higher (B_u times)
- The computational load in the BS-scheduler is significantly higher
- An alternative, to decrease the uplink signaling traffic: to transmit only the M bins which are predicted to have the best SINR values;
  - The uplink message should contain the bin-index (6 bits), predicted SINR value (8 bits) multiplied by M $\Rightarrow$ signaling rate $R_{SOA\text{-}M} = M \times (6+8) \times D_{bin}$ = 117 kbps/user, for M = 5, still high.
- The compression of the signaling information leads to:
  - Additional processing both in the MS and BS
  - Increased sensitivity to errors on the uplink
  - Insertion of a more powerful FEC

CONCLUSIONS

- The theoretical and simulation-based evaluations show that the Optimal Allocation bin-allocation method ensures throughputs (spectral efficiencies) significantly higher than the ones provided by the Frequency Hopping method
- The uplink signaling bit-rate required by the OpAl method is very high, while the one required by the FH method is small.
- The computational load required by the OpAl is significantly higher than the one required the FH, both in MS and BS.
- To compensate these drawbacks, two possible solutions are suggested:
  - To decrease the amount of information transmitted by the mobile station on the uplink; this modified OpAl method could ensure about the same performances, but the signaling bit-rate would still be rather high.
  - To compress the signaling information; this methods also has shortcomings.
- The FH method combined with the set of LDPC-coded QAM modulations ensures about the same spectral efficiency as the OpAl combined with non-coded QAM (provided that the L(2,q) codes would be replaced with L(3, q) codes);
- This option could offer a reasonable trade-off between the throughput provided, on one hand, and the signaling traffic and computational load in the mobile station, on the other hand.
- The LDPC-coded set of modulations provides significantly higher throughputs than the non-coded set.

References

- [1] R.Dineen – *Flarion Technologies*” Ovum 2004
- [2] M. Sternad, T. Ottosson, A. Ahlén, A. Svensson, “*Attaining both coverage and high spectral efficiency with adaptive OFDMA downlinks*,” in *Proc. IEEE VTC 2003 Fall*, Orlando, USA, October 2003.
- [3] W.Wang, T.Ottosson, M.Sternad, A.Ahl’en, A.Svensson - “*Impact of Multiuser Diversity on Adaptive OFDM*” VCT 2003-Fall, Orlando, USA, October
- 2003
- [4] V.Bota, M.Varga, Zs.Polgar – “*Performances of LDPC-Coded OFDM Transmissions and Applications on Fixed and Mobile Radio Channels*”, COST 289 MCM, Barcelona, 2004.
- [5] V.Bota, Zs.Polgar, M.Varga – “*Simulation Programs for the Evaluation of the LDPC-Coded Multicarrier Transmissions*”, Workshop of COST 289,
- Budapest, 2004
- [6] Th. S. Rappaport – “Wireless Communications. Principles and Practice”, IEEE Press, Prentice Hall, 2001
- [7] D.Knuth, The Art of Computer Programming, vol.II, Addison-Wesley, 1981