

Optimisation of Enhanced UMTS Cellular Planning Based in Economic Aspects

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Abstract – Based in a definition of simulations scenarios, traffic behaviour, and QoS (Quality of Service) aspects, a SLS (System Level Simulator) is used for obtaining system capacity results for urban and business city centre (BCC) scenarios, when overload conditions are considered. Optimum values of the cell coverage distance that maximise the profit per unit length (in BCC) or by unit area (urban) were found. For prices of 5 and 7 Euro cents/MB, while in urban scenarios, optimum values of 70 % and 140 %, respectively, were found for profit (for a coverage distance of ~414 m), in BCC, optimum values occur around 240m, and are 80 and 150 %, respectively.

I. INTRODUCTION

This paper focuses the possible enhancements to 3rd Generation mobile communications systems for the downlink and uplink directions (with HSDPA and HSUPA, High Speed Downlink/Uplink Packet Access). It deals with a UMTS, Universal Mobile Telecommunication System, and its evolution to E-UMTS, Enhanced UMTS, which encompass radio interface, access network, and core network. Enhancements will allow supporting data rates up to 8-10 Mb/s in both directions, and include, among others, advanced modulation and radio transmission techniques, improved strategies for IP routing and QoS (Quality of Service) assurance at the radio access and core networks. The effect of these enhancements will be evaluated by means of simulation.

For that purpose a set of services need to be used, in order to create a complete and realistic simulation framework, impacting directly on traffic generation models. These services will be accessed from a variety of operation environments each with its distinctive set of service preferences, usage patterns, and associated mobility profiles. As an answer to these services and environmental conditions a matching set of deployment strategies have been studied, adapted, and simulated.

Terminal mobility has a great influence in most UMTS communication aspects involving either performance or traffic generation as a result of handover. Issues such as radio resource management, location management and QoS, as well as traffic handling capacity, are directly affected by mobility. The purpose of mobility models is to describe typical terminal movement for performance analysis purposes. Many link level simulations require the knowledge of detailed terminal

position so that the effectiveness of studied techniques such as link adaptation (adaptive coding and modulation) transmission diversity, and beam forming may be evaluated.

E-UMTS services classification and characterisation [1] were proposed in the context of the European project IST-SEACORN (Information Society Technologies Simulation of Enhanced UMTS Access and Core Network). This work included aspects regarding quality of service, as well as a definition of simulation scenarios to be used within the SLS, System Level Simulator, developed by the project [2].

The purpose of this work is to optimise the cellular planning process for multi-service E-UMTS in outdoor environments by using results for system capacity as an input for a cost/revenue function, e.g., to choose the best coverage distance of cells.

Section II describes the simulation scenario, including scenarios of mobility, and the details on urban and Manhattan topologies. Service characteristics, source traffic, and activity models are presented as well. Section III presents details on system capacity, e.g., throughput, taking delay, blocking and handover failure probabilities thresholds into account. The cost/revenue model is presented in Section IV, including assumptions for prices, in terms of volume of information. In Section V, by using these models, optimum values are found for the coverage distance, which maximise the profit. Finally, conclusions are drawn in Section VI.

II. SIMULATION SCENARIOS AND SOURCE TRAFFIC

The urban scenario represents urban and suburban environments (outside the city centre). Its main simulation parameters/characteristics [3] are presented in Table I. The mobility model is the Gauss-Markov mobility model, which is an entity mobility model, as it defines individual and not group movement patterns. The pattern is confined within the predefined grid area. As in all mobility scenarios, the users are confined within this area and return to a point inside the topology when they reach the boundaries. It is defined to be between the random walk (slow speeds) and the fluid flow (very high speeds) models. The two models, random walk and fluid flow are labelled as extremes. Most of the nodes moves somewhere in between those speeds.

TABLE I
MAIN SIMULATION PARAMETERS.

Parameters	Values	
	Urban	BCC
Average user velocity	50km/h	3km/h
Minimum user velocity	-	0km/h
Direction update	20m	5m
Probability to change direction in position update	0.2	0.2
Maximum angle in position update	45°	0.5
Number of base stations	7	9
Cell coverage distance	[350, 600]m	[25, 500]m
BS Antenna	Tri-sectorial	Omnidirectional
Maximum BS Tx power	16dBW	13dBW
Antenna gain	17.5dBi	0 dBi
UE transmit power class [dBm]	33,27,24,21 (default) dBm	
Number of users	5000	[500, 1000]
Interval between successive calls	0.005s	
Simulation time	180s	

Parameters for the Gauss-Markov model include the mobile speed at 50 km/h (13.89 m/s), and a random seed, a number that is fed into a random number generator, as this model aims to assign pseudorandom paths to the mobile users, Table I (first four parameters). The position actualisation is performed within relatively larger space steps, at each 20 meters, due to higher velocities [4]. The Radio Propagation model used is the Hata propagation model [5].

In the urban scenario, simulations consider seven macrocells ($N_{cells}=7$), Fig. 1, using tri-sectorial antennas and one single amplifier, and a variation of the cell coverage distance, R , from 350m to 600m. The user density (number of users per square meter), σ , remains unchanged during simulations, thus the number of users varies because the geometry area increases with R .

To represent BCC (business city centre) scenarios the Manhattan Model is normally used, Fig. 2, and consists of a rectangular grid of intersecting streets. Homogeneous squared buildings, with 200 m side and 30 m wide streets, characterises the environment. This sort of environment is characterised by relatively small street areas with high buildings, high user density and low mobility (pedestrians). Its simulations characteristics are presented in Table I

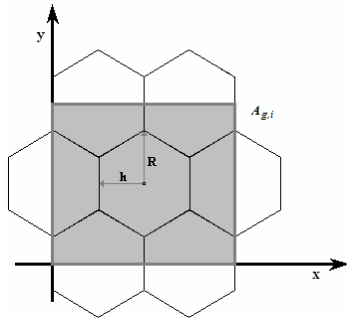


FIGURE 1: 7 CELL GEOMETRY FOR THE URBAN SCENARIO.

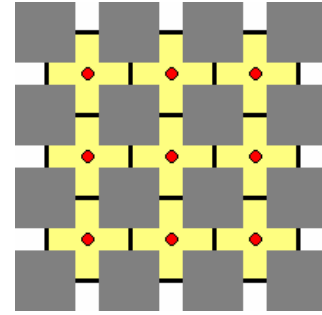


FIGURE 2: MANHATTAN TOPOLOGY MODEL.

In BCC scenarios the mobile units move along the streets and can change direction in crossroads following a certain probability. The position actualisation needs to be performed with some frequency; since pedestrian velocities are considered in this environment, an actualisation at each 5 meters is reasonable. At each position actualisation a velocity variation may occur according to a given probability. The Radio Propagation model is the Walfisch propagation one [5], and omnidirectional antennas are used.

In Table II, R_b represents the data rate for each considered application while the usage represents the percentage of E-UMTS applications users for URB and BCC scenarios [1]. Examples of applications in each class are VOI-voice, VTE-Videotelephony, MWB-Multimedia Web Browsing, and ATR-Assistance in Travel.

TABLE II
E-UMTS APPLICATIONS DATA RATE AND USAGE.

Services and Applications	R_b [kb/s]	τ [min]	Usage [%]	
			Urban	BCC
Sound (e.g., VOI)	12	3	79.2	27.0
Multimedia (e.g., VTE)	144	3	11.6	16.0
Narrowband (e.g., MWB)	384	15	4.1	26.0
Wideband (e.g., ATR)	768	20	5.1	31.0

Table III presents the service characteristics of these applications (TB-time based, NTB-non TB, RT-real time, NRT-non real time, Bid-bidirectional, Sym-Symmetric, Asy-Asymmetric).

TABLE III
ENHANCED UMTS SERVICE CHARACTERISTICS [6].

Applications	Intrinsic time dependency	Delivery requirements	Directionality	Symmetry / Asymmetry
VOI	TB	RT	Bid	Sym
VTE	TB	RT	Bid	Sym
MWB	TB	RT	Bid	Asy
ATR	TB	RT/NRT	Bid	Asy

The model for traffic mix defined for these environments generates traffic according to the predefined usage

percentages, and assigns an application to each user accordingly. Each user has a probability to be active. This is determined by the Busy Hour Call Attempts (BHCA), provided as a set of bounds for the percentage of active users in a simulation run. Session activity parameters describe the detailed aspects of traffic within a call. This is accomplished by means of an alternating active/inactive state model (ON/OFF). By defining an average duration of each period, together with an adequate statistical distribution (e.g., reflecting long-range dependence), the activity within a call can be modelled. The model is based on population and service penetration values in order to determine call generation rates for the constituent services within each of the selected scenarios.

The activity within a call is modelled by defining an average duration of each active/inactive period, together with an adequate statistical distribution. The basic model for application data normally uses a Web session as a paradigm, although the model may be used for all types of data. A session is composed of a set of active periods made of packet sequences (packet calls) separated by inactivity periods. A packet call is a sequence or burst of packets, corresponding, e.g., to a Web page or other data item. Inactivity periods between packet call arrivals are often called reading or inactivity time. Table IV describes average active versus inactive durations, and presents the statistical distributions of the active and inactive durations.

TABLE IV
APPLICATION ACTIVITY PARAMETERS.

Applications	Active state (ON)		Inactive state (OFF)	
	Avg.[s]	Distrib.	Avg.[s]	Distrib.
Sound	1.4s	Expon.	1.7 s	Expon.
HIMM	10	Expon.	10	Expon.
Narrowband	10	Pareto	13	Pareto
Wideband	10	Expon.	10	Expon.

III. SYSTEM CAPACITY

A. Urban

QoS (Quality of Service) measures include blocking probability, handover failure probability, end-to-end delay (latency), and throughput. In this work one presents results for the URB (urban/vehicular) and BCC (business city centre) scenarios. Active users start their sessions in a small initial period, remaining active during all the simulation time (180s), unless call losses occur (e.g., due to handover failure). By varying f , and for each cell radius ($R \in [350, 600]$ meters) several values were obtained where at least one of the QoS parameters (latency, blocking and handover failure probabilities) exceeds its maximum threshold (150 ms, 2%, and $(P_{hf})_{max}$, respectively, the latter corresponding to a

maximum call dropping probability of 0.5%). The minimum values of the overlapping curves for the three restrictive conditions represent the maximum fraction of active users supported, Fig. 3.

These values of R will be considered in the computation of system throughput (by using results for throughput obtained from the simulation), Fig. 4, which, in turn, will be used as an input for the revenue function. Fig. 5 presents the resulting supported throughput per square kilometre, as a function of R . It is approximately constant from 370 to 420 m, with an optimum around 410-420 m, where a throughput of 2546kb/s/km² is achieved. For coverage distances higher than 420 m the throughput starts to decrease.

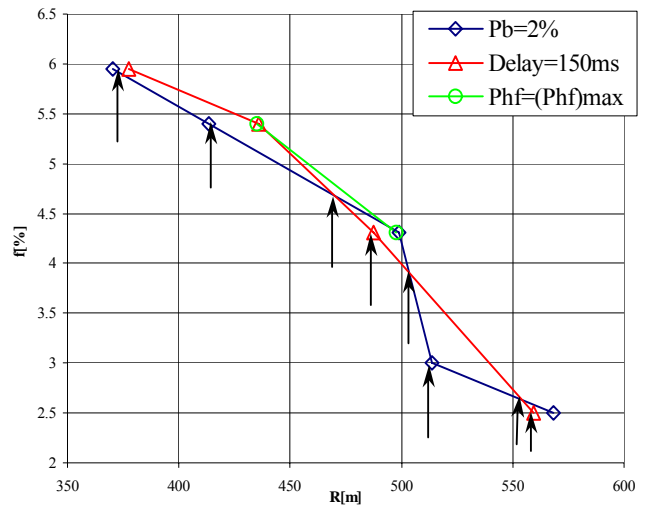


FIGURE 3: FRACTION OF ACTIVE USERS AS A FUNCTION OF R FOR THE THREE RESTRICTIVE CONDITIONS, URB SCENARIO.

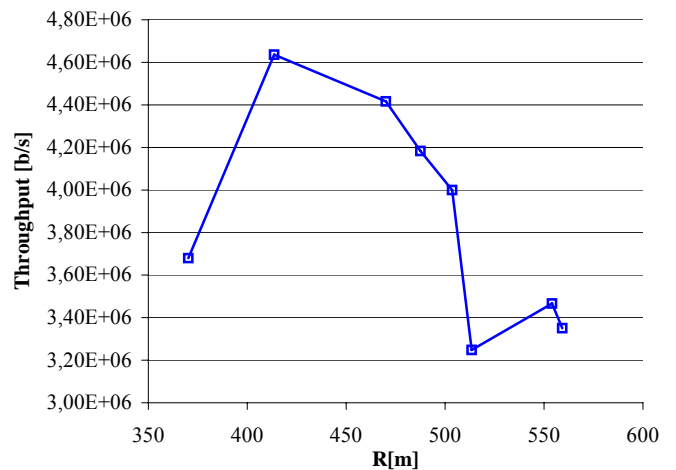


FIGURE 4: THROUGHPUT AS A FUNCTION OF R , URB SCENARIO.

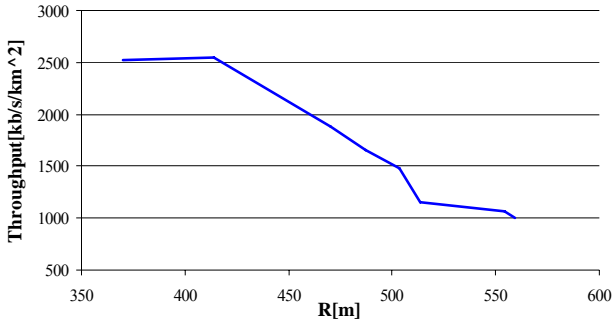


FIGURE 5: THROUGHPUT PER KM^2 AS A FUNCTION OF R , URB SCENARIO.

B. Business City Centre

BCC scenario represents the system behaviour in a Manhattan type outdoor environment with microcells and omnidirectional antennas, assuming 9 base stations. Some parameters varied in simulations in order to study their influence on system performance. These parameters include the number of users, M , and the distance between base stations (n.b. because streets are tessellated in between blocks of buildings the dimensions of the covered area depends on the distance, being, therefore, variable). A situation is simulated in which all active users initiate a session during a small initial period (within the 180 s of simulation time). The users remain active until the end of the simulation time, unless call losses occur due to handover failure.

Values for the QoS parameters were obtained by varying the number of users, $M \in [500, 1000]$, for each cell coverage distance, $R \in [25, 500]$ m. To perform this analysis, one determines the values of R and f (fraction of active users) where the thresholds for the latency, the blocking probability, and the handover failure probability are reached.

A reference geometry of 900×900 meters was considered, with cells of $R = 150$ m. A normalisation/transposition from simulation results obtained with geometries of different dimensions, corresponding to different cell coverage distance, R , to this reference geometry was performed. This is justified because, as cells are tessellated in between blocks of buildings, for each R , in the usual BCC scenarios approach, there are different dimensions for the block of buildings because the length of the blocks of buildings is $2R-l$, where l is the street width.

By analysing the results, one concludes that, in geometries with an area equal to the one of the reference geometry, for cell radius below 100 m, latency, and handover failure probability are limitative. Therefore, in this kind of geometry, to enable the use of microcells with radius below 100 m, mechanisms to attenuate the effect the excess in these parameters must be developed.

For higher cell coverage distances, an optimum is observed in terms of throughput per kilometre around 240-250 meters, corresponding to a value of the throughput of 1460 kb/s/km, Fig. 6. For higher cell radius, the throughput decreases even more, which allows to conclude that the utilisation of cells with radius above 250 meters may not be an advantage.

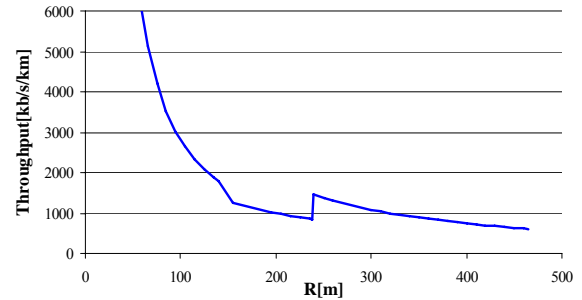


FIGURE 6: THROUGHPUT PER KM AS A FUNCTION OF R , FOR BCC SCENARIO.

IV. COST/REVENUE MODEL

A. Urban

In this work, we consider the operator/service provider's point of view [7]. Both in URB and BCC scenarios, a cost/revenue function was developed taking into account the cost of building and maintaining the infrastructure, and the way the number of channels available in each cell affects operators' revenues. Fixed costs for licensing and bandwidth auctions should also be taken into account. Although one considers a project duration of five years as a working hypothesis, one will analyse costs and revenues on an annual basis. Furthermore, the analysis is made under the assumption of null discount rate [8]. By no means is it intended to perform a complete economic study but only to present initial contributions. Appropriate changes would be needed to perform a complete economic analysis based on discounted cash flows (e.g., to compute the net present value).

The system costs includes a fixed term that represents the fixed costs, C_f , and one term proportional to the number of base stations, C_b (although there is a term proportional to the number of carrier of a base station, in this work approach, only one carrier is considered, and this is incorporated in C_b).

The total cost per unit area is given by

$$C_{[\epsilon/\text{km}^2]} = C_f[\epsilon/\text{km}^2] + C_b[\epsilon] \frac{N_{\text{cells}}}{A_{g,i}[\text{km}^2]}, \quad (1)$$

where N_{cells} is the number of cells in a given area for the geometry, $A_{g,i}$.

The annual revenue per area unit is given by

$$R_v[\epsilon/\text{km}^2] = P_{[\epsilon/\text{kb}]} \cdot Q_{[\text{kb}]} / A_{g,i}[\text{km}^2] \quad (2)$$

where p represents the price per kb of data, and Q is the load of the system, which is obtained by

$$Q_{[kb]} = Thr_{[kb/s]} \cdot t_{BHCA[s]} \quad (3)$$

where Thr is the throughput of system, and t_{BHCA} is the total time/duration of the busy hour call attempts, i.e., one considers an equivalent daily period in overload conditions that represents the whole day behaviour as an average situation. The annual period corresponding to this busy hour call attempts, t_{BHCA} , is obtained by considering 6 equivalent busy hours per day during 250 days per year, i.e., 5400000 seconds per year.

B. Business City Centre

BCC scenario has a regular geometry (Manhattan) which allows for an analysis similar to the linear geometry. Hence, by using a 'linearised' approach which only considers one of the perpendicular streets [8], the total cost per unit of length is given by

$$C_{[\epsilon/km]} = C_{f[\epsilon/km]} + C_{b[\epsilon]} \frac{1}{2R_{[km]} - \frac{l_{[km]}}{2}}, \quad (4)$$

where l is the street width of the Manhattan geometry. The annual revenue per unit of length is given by

$$R_{v[\epsilon/km]} = \frac{P_{[\epsilon/kb]} \cdot Q_{cell[kb]}}{2R_{[km]} - \frac{l_{[km]}}{2}}, \quad (5)$$

where p represents the price per kb of data, and Q_{cell} the load supported by a cell during a year, which is obtained by

$$Q_{cell[kb]} = \frac{Thr_{[kb/s]} \cdot t_{BHCA[s]}}{N_{cells}}. \quad (6)$$

Note that $Q_{[kb]} = N_{cells} \cdot Q_{cell[kb]}$, where N_{cells} is the number of cells for the 'linearised' geometry.

V. OPTIMISATION

A. Urban

The values for costs and prices may vary meaningfully from country to country and between network operators. In this research one considers hypotheses for the Portuguese case. On the one hand, one considers $C_f = 361.7$ €/km²/year, and $C_b = 12500$ €/year [9]. On the other, revenues depend on the volume of information. One considers the hypotheses from Table V for the price per MB, p (in €/MB).

TABLE V
HYPOTHESIS FOR THE PRICES PER MB.

Hypotheses	p [€/MB]	p [€/kb]
Hyp. I	0.03	3.66211E-06
Hyp. II	0.05	6.10352E-06
Hyp. III	0.07	8.54492E-06

Fig. 7 presents the costs/revenues per km² as a function of R , for the three hypotheses for prices, Table 3, (n.b. costs does not depend on the hypothesis for revenues).

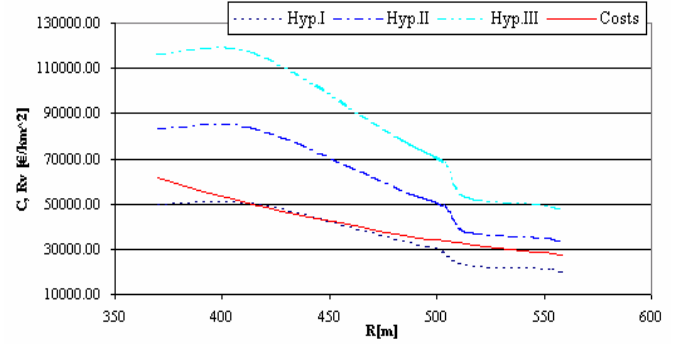


FIGURE 7: COST/REVENUES PER KM² AS A FUNCTION OF R , FOR THE THREE HYPOTHESIS FOR PRICES.

One verifies that only for a price of 5 and 7 cents per MB (Hyp. II and III), the revenues totally overcome the considered costs, Fig. 7. Hence, in urban scenarios it is possible to obtain a profit near 150% for the most optimistic hypothesis. It was obtained for a cell coverage distance near 414m, Fig. 8.

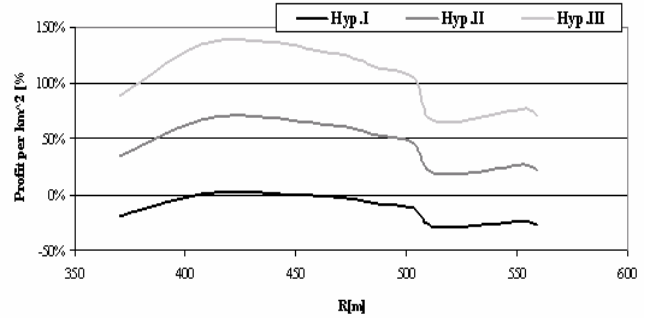


FIGURE 8: PROFIT PER KM² AS A FUNCTION OF R , FOR THE THREE HYPOTHESIS FOR PRICES.

B. Business City Centre

By considering the same hypothesis for prices per MB as in the urban scenario, Table V, in the range of values for R to which the latency and the handover failure probability are not limitative, an optimum was found at $R \approx 240$ m, where the profit (per cell or per kilometre) presents a maximum, Fig. 9. Coverage distances lower 100 m are not considered because of handover failure probability and latency restrictions.

However, cell radius up to ~ 260 m can be used without a significant decrease in terms of profit. For these coverage distances, BCC scenarios take clear profitable configurations for Hyps. II and III for prices; profit is approximately 80 and 150 %, respectively.

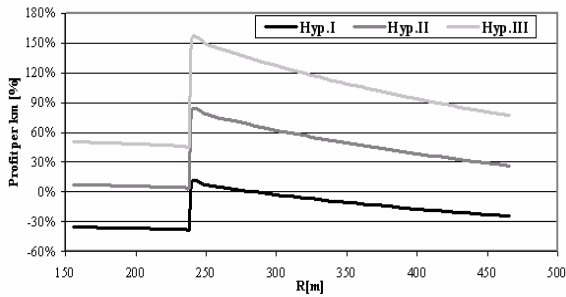


FIGURE 9: TOTAL PROFIT PER KM FOR BCC, IN PERCENTAGE

VI. CONCLUSIONS

Based in a definition of simulations scenarios, source traffic characteristics, activity/inactivity behaviour during a call/session, and QoS (Quality of Service) aspects, the SLS (System Level Simulator) developed within IST-SEACORN (Simulation of Enhanced UMTS Access and Core networks) is used for obtaining system capacity results for urban and business city centre (BCC) scenarios.

Conclusions on Enhanced UMTS cellular planning optimisation were obtained when overload conditions are considered in urban scenarios. From the results for the throughput per km^2 , which is flat from 370 to 420 m, and then decreases substantially, optimum values were found for the cell coverage distance, which maximises the profit per unit area, in percentage. By defining the profit as the difference between revenues and costs optimum values between 405 and 440m were obtained for the coverage distance, the maximum profit being obtained for $R=414\text{m}$. Optimum values for the profit are approximately 70 and 140 % for Hyps. II and III for prices, i.e., $p = 0.05$ and 0.07 €/MB .

In the BCC scenario, for the considered hypothesis, revenues exceed the costs for cell radius below 140 m as well as for cell radius higher than 240 meters. By defining the profit as the difference between revenues and costs, optimum values between 240 and 260m were obtained for the coverage distance, the maximum being obtained for $R \approx 240\text{m}$. Hyps. II and III are clearly profitable ones.

ACKNOWLEDGEMENTS

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