Appendix B

Single Channel Receiver DCA Simulation

This simulation was run under the assumption that single channel mobile terminals were being used so that mobile terminals could not maintain communications links whilst measuring interference on target handover channels. Handover has to happen rapidly to avoid long drop-outs in the communications link and therefore a limit of five different channels was set on the number of channels for which a mobile terminal would measure interference power at handover. The number of initial requests to FESs made by a mobile was also limited to through five different satellites.

B.1. System Capacity

The maximum operational capacity of the system is determined by choosing acceptable levels of service for call blocking and dropping probabilities, the quality of the communications channel and the overall throughput of the system. Statistics are collated for all of these parameters. Remember that "mean requested calls in progress within mobility area" is the unit of traffic intensity and is the mean number of calls that would be in progress within the mobility area *if all call requests were successful and all calls continued through to normal completion*, i.e. no calls are blocked or dropped. This unit cannot be expressed in Erlang because Erlang is relative to system capacity, which is an unknown.

B.1.1. Blocking Probability

The co-location of the 0°North and 30°North blocking probability curves in figure B1 show that at low latitudes the system capacity is being limited by the 100 channel spectral resource rather than the satellite configuration and that the channel assignment scheme is consistently able to initially find a spare channel. The 60°North curve shows an increase in the probability of a channel not being found, as would be expected when the number of options increases but the time available to search through them remains limited by the five satellite limit. The blocking probability would rise further in regions further from the equator as satellite ground tracks converged closer together, increasing the range of satellites the mobile terminal could choose from.

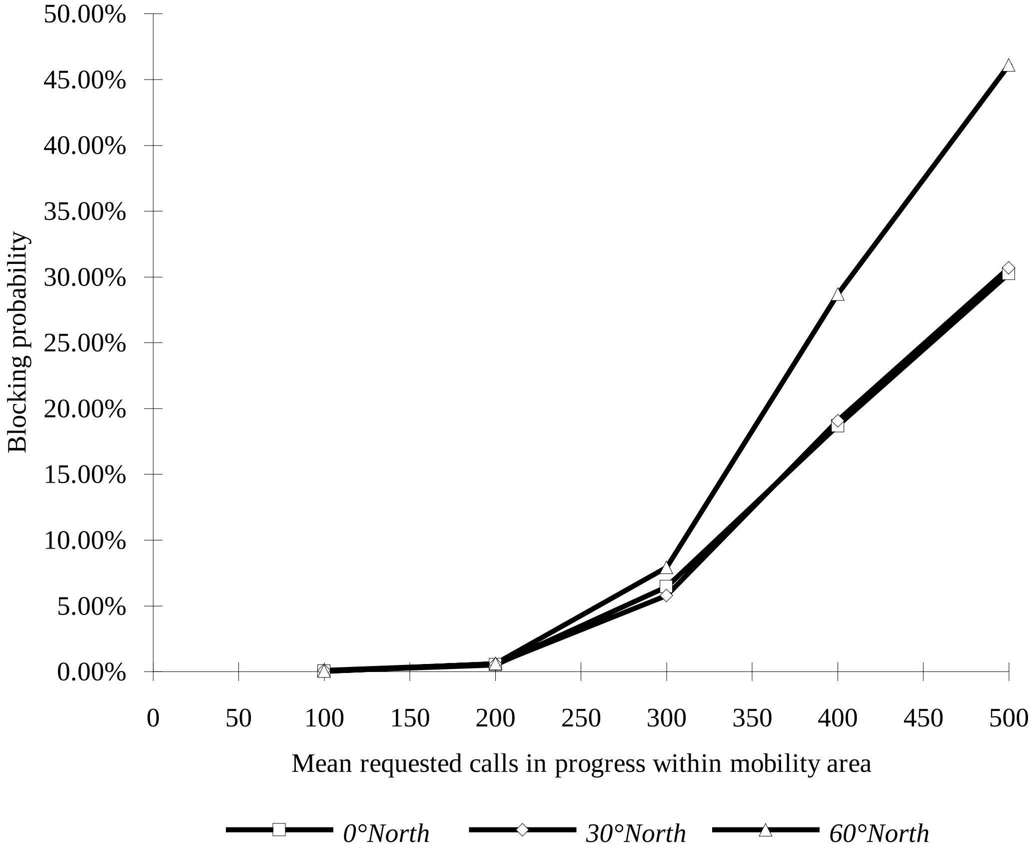

Figure B1 Blocking probability as a function of traffic intensity

For a 2% blocking probability the results in figure B1 show the system to be capable of handling up to approximately 225 calls in progress requested per 69,360,000km^2. Figures B2 to B4 show that this is a pessimistic basis on which to size the capacity of the network, as the dropping probability is more relevant once a call is in progress. The probability of a call being initially blocked is influenced by maximum number of satellites to which the call request can be made and is set to 5 in this simulation. Setting its value this low ensures that call set-up is rapid but the speed of call set-up is not really critical as communication has not yet started. Appendix section C.1.1 shows how the blocking probability is improved when this limit is raised and that the call blocking probability can be brought to below 2% for traffic intensities as high as 300 calls per 69,360,000km^2 by raising this limit to 20.

B.1.2. Call Dropping Probability

The probability of a call being dropped, shown in figure B2, is comfortably below 2% for traffic intensities to over 300 calls/69,360,000km^2. The dropping probability reflects the limitation of the maximum number of channel measurements that the mobile terminal can make on a satellite link before trying another satellite. As this simulation assumes the use of single channel receivers this value has to be kept low to prevent long interruptions at handover and therefore the dropping probability curves reflect the capacity limitation of this single channel receiver scheme.

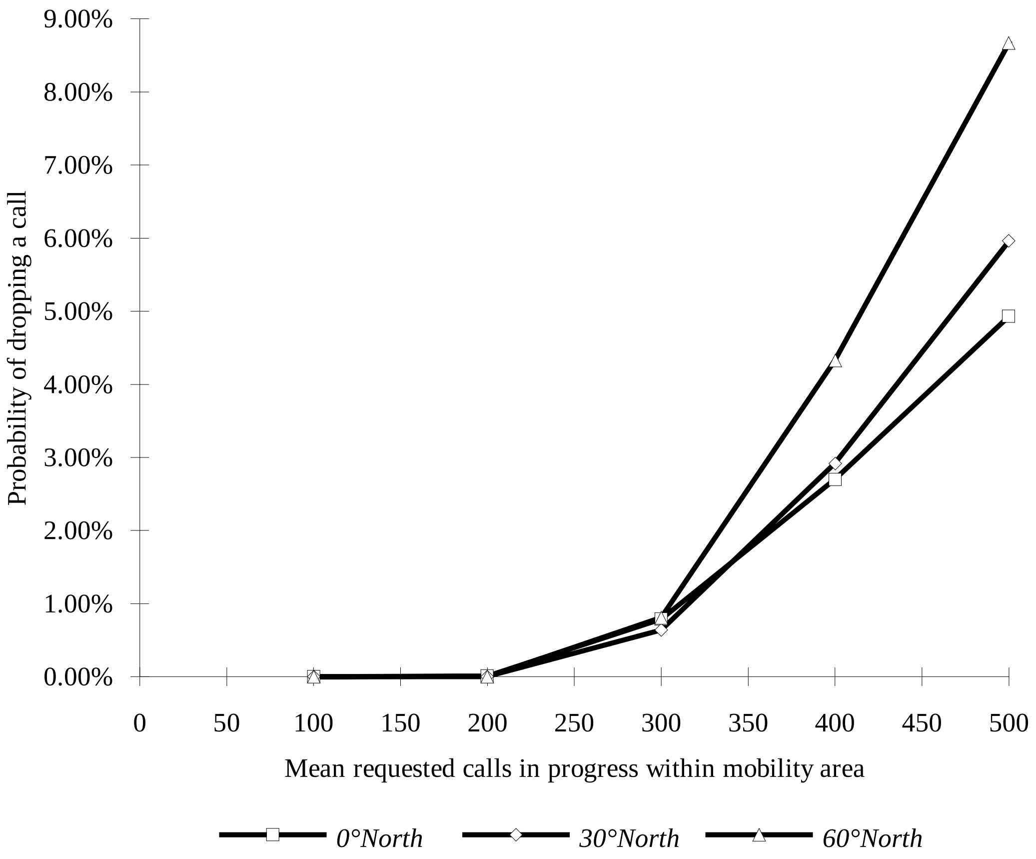

Figure B2 Call dropping probability as a function of traffic intensity

The spread of the three curves at different latitudes shows that the geometry of the satellites affects system capacity. Where satellite coverage overlaps, channel assignment is more likely to fail because of the confused interference pattern, which makes the FES predictions less reliable and hence more channel proposals made by the FES to mobile terminals will be rejected by the mobile terminals. As the number of proposals is being limited, the probability of the limit being reached and channel assignment failing is higher.

B.1.3. Probability of Channel Suffering Poor Quality

Three C/I thresholds, C/I_{block}, $C/I_{try\ handover}$ and C/I_{min}, and three received power thresholds, $power_{block}$, $power_{try\ handover}$ and $power_{min}$ were used in the simulation. A call suffering poor quality is defined as one that has a C/I between $C/I_{try\ handover}$ and C/I_{min} or a received power between $power_{try\ handover}$ and $power_{min}$. In other words, the call should really be handed over (and handovers are being attempted but rejected for some reason) but channel quality has not yet fallen so low that the call has been dropped.

The curves shown in figure B3 follow the pattern of the dropped call curves, for the same reasons. The probability of a call suffering from poor quality is less than $^1/_{20}$ of the probability of dropping the call, perhaps an indication that handover is being left too late, so calls are dropped at the edge of satellite coverage because insufficient time was left to find a new channel.

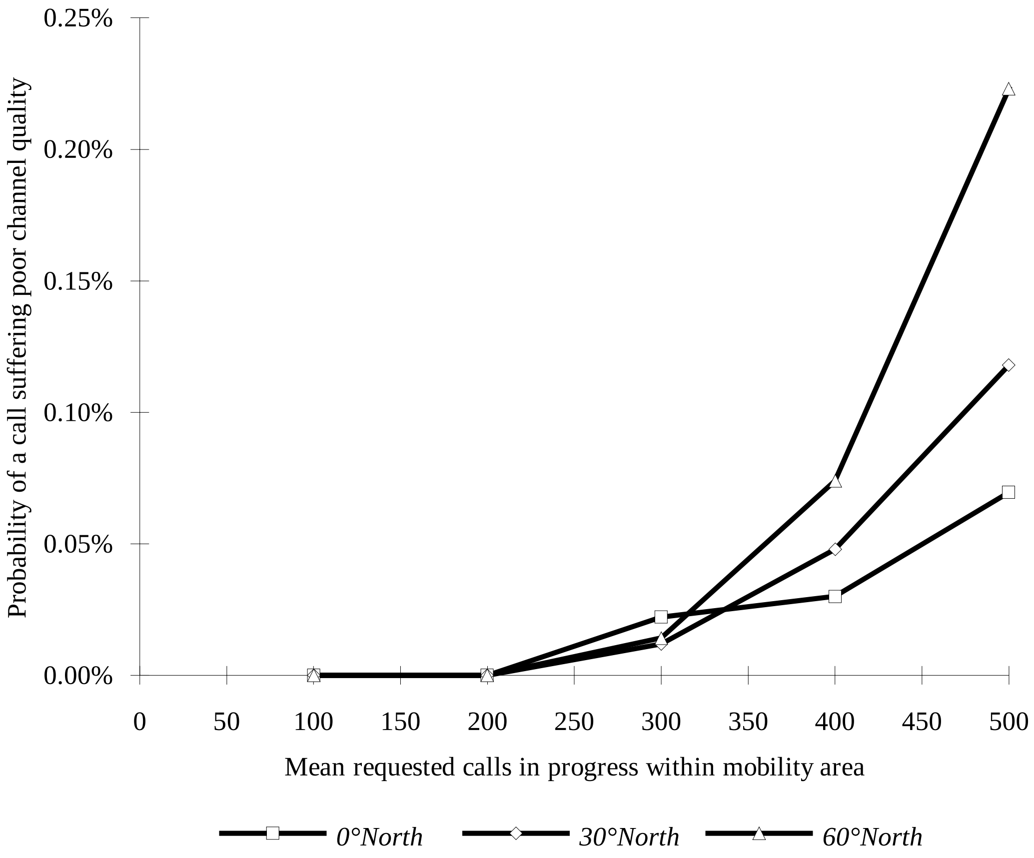

Figure B3 Probability of a call suffering poor channel quality as a function of traffic intensity

B.1.4. Actual Carried Traffic per Satellite

Figure B4 illustrates the number of calls being carried by the satellites. The difference in carried traffic between satellites at different latitudes is apparent from there being more satellites over the same area of ground at higher latitudes, all sharing the same density of offered traffic below. What is curious is that instead of the curves rising to a plateau as the system becomes saturated, the capacity of the system *reduces* as the system becomes overloaded, indicating that calls that are being carried are resulting in a higher level of interference overall, causing more calls to be blocked and dropped. Figures B5, B6 and B7 show the proportions of requested calls that result in blocked calls, dropped calls, poor quality calls and successful calls at the three simulated latitudes.

Peak capacity appears to occur at a traffic intensity approaching 300 calls per 69,360,000km^2, which would provide service with a call dropping probability of about 0.8%. Whilst this may seem low, it represents 4.3 channels/1,000,000km^2/MHz (assuming 10kHz/channel) which is the same order of magnitude as Iridium's 7 channels/1,000,000km^2/MHz, Globalstar's 3 channels/1,000,000km^2/MHz, Odyssey's 1.5 channels/ 1,000,000km^2/MHz and Inmarsat-P's 1 channel/1,000,000km^2/MHz.

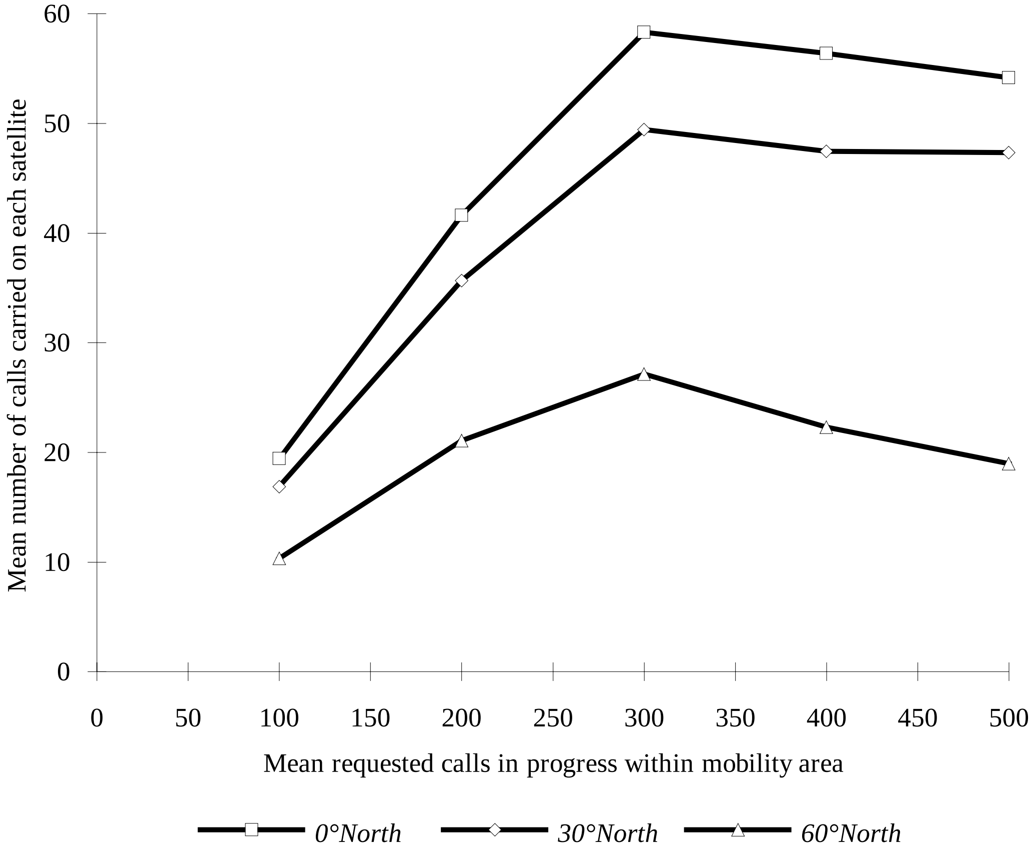

Figure B4 Mean number of calls carried per satellite as a function of traffic intensity

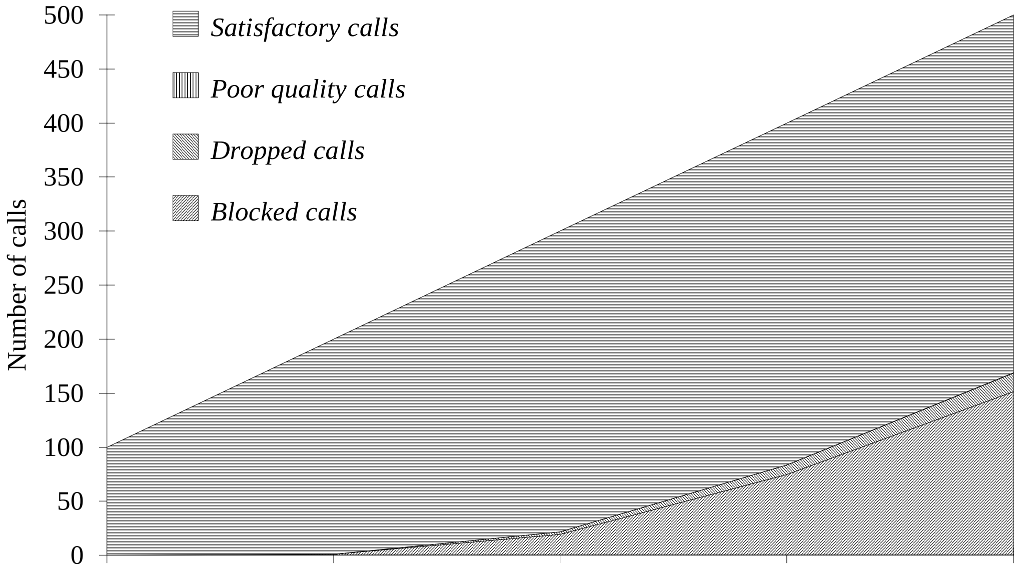

Figure B5 What happens to call requests at 0°North

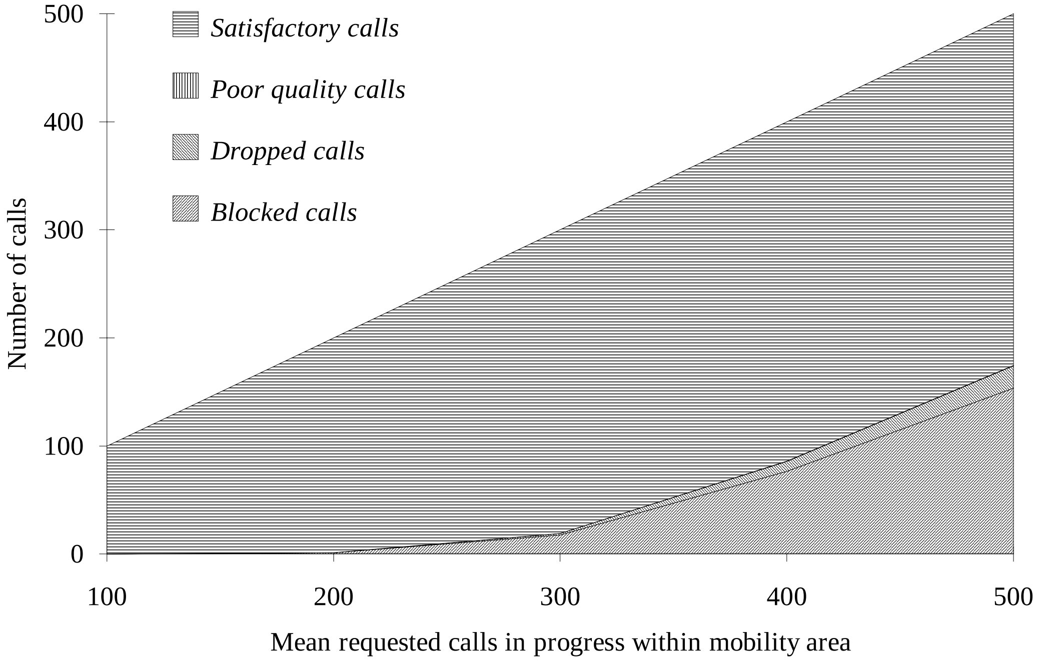

Figure B6 What happens to call requests at 30°North

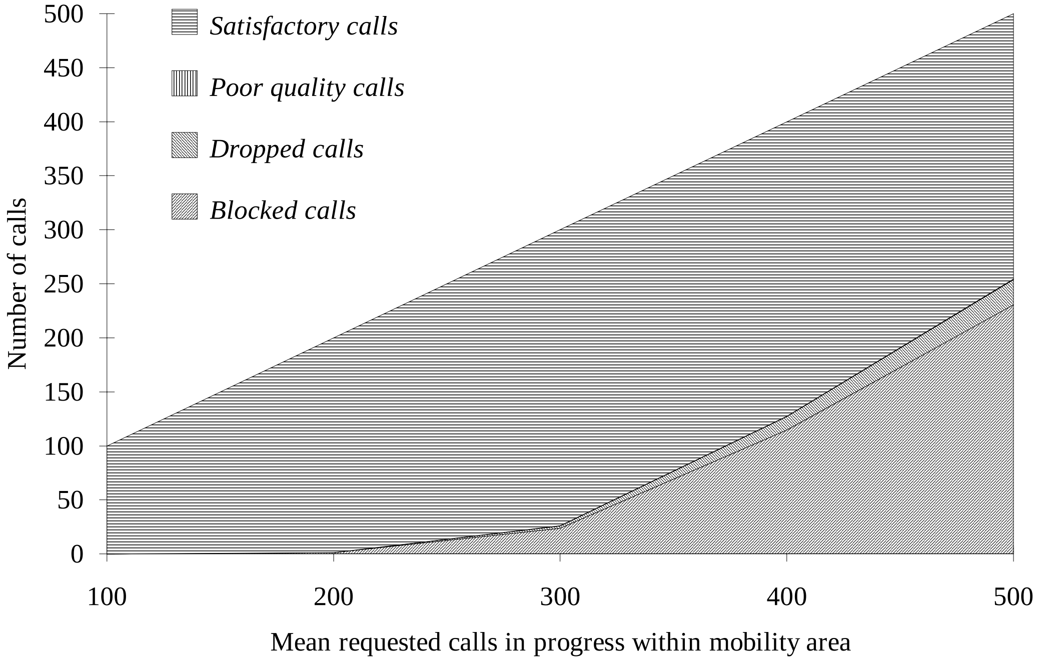

Figure B7 What happens to call requests at 60°North

B.2. Handover Interruptions

The simulation records intra-satellite and inter-satellite handovers separately and figure B8 shows the frequency of these handovers. Many handovers are intra-satellite and are executed very rapidly, as is shown in figure B9. However at least half of the handovers were from one satellite to another, which in this simulation always involved a change of FES. These inter-FES handovers took much longer to execute, as shown in figure B10. Tables B1 and B2 tabulate the worst case simulation handover performance.

B.2.1. Mean Time Between Handovers

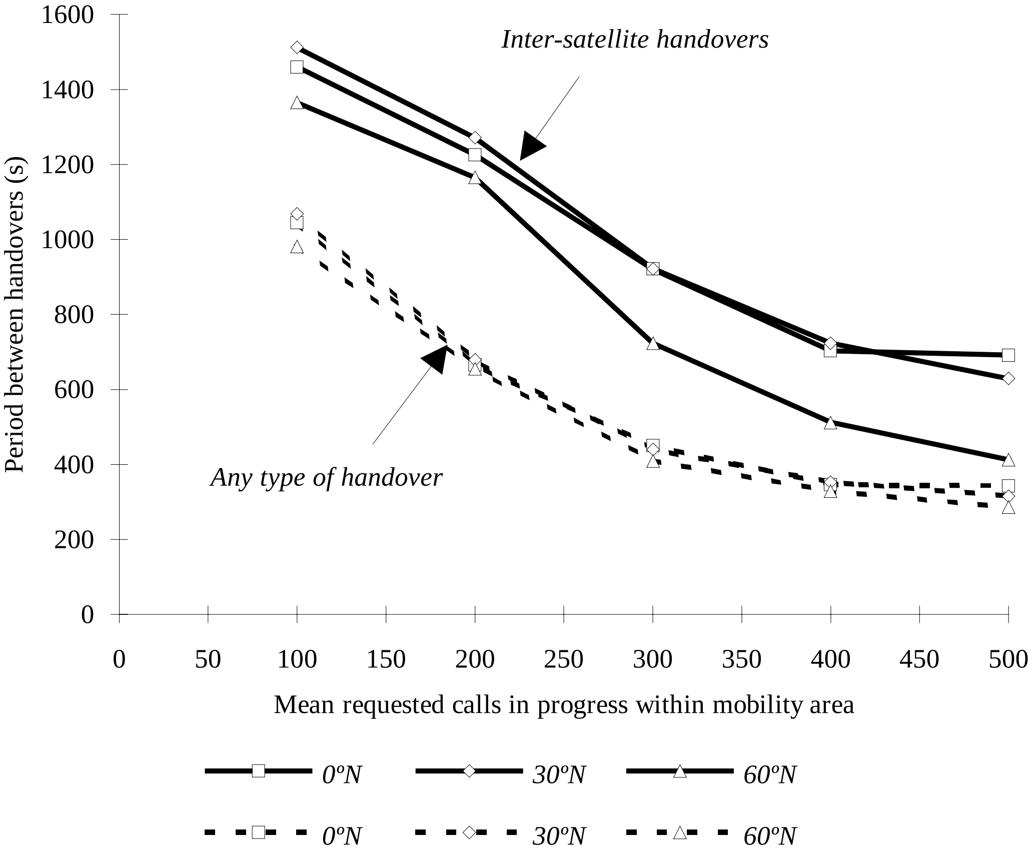

Figure B8 Mean time between handovers as a function of traffic intensity

As the system becomes more congested the potential for self-interference increases resulting in an increase in handover activity. At 300 calls per 69,360,000km^2 handovers would be occurring on average once every seven minutes and roughly every other handover would be to a new satellite. At more northern latitudes the frequency of inter-satellite handovers increases because the greater overlap between different beams' coverage introduces more interference between transmissions. Whenever a receiver experiences interference rising above the threshold for handover it initiates handover, so when interference is at a high level and changes rapidly handovers occur more often.

B.2.2. Channel Drop-out Duration at Handover

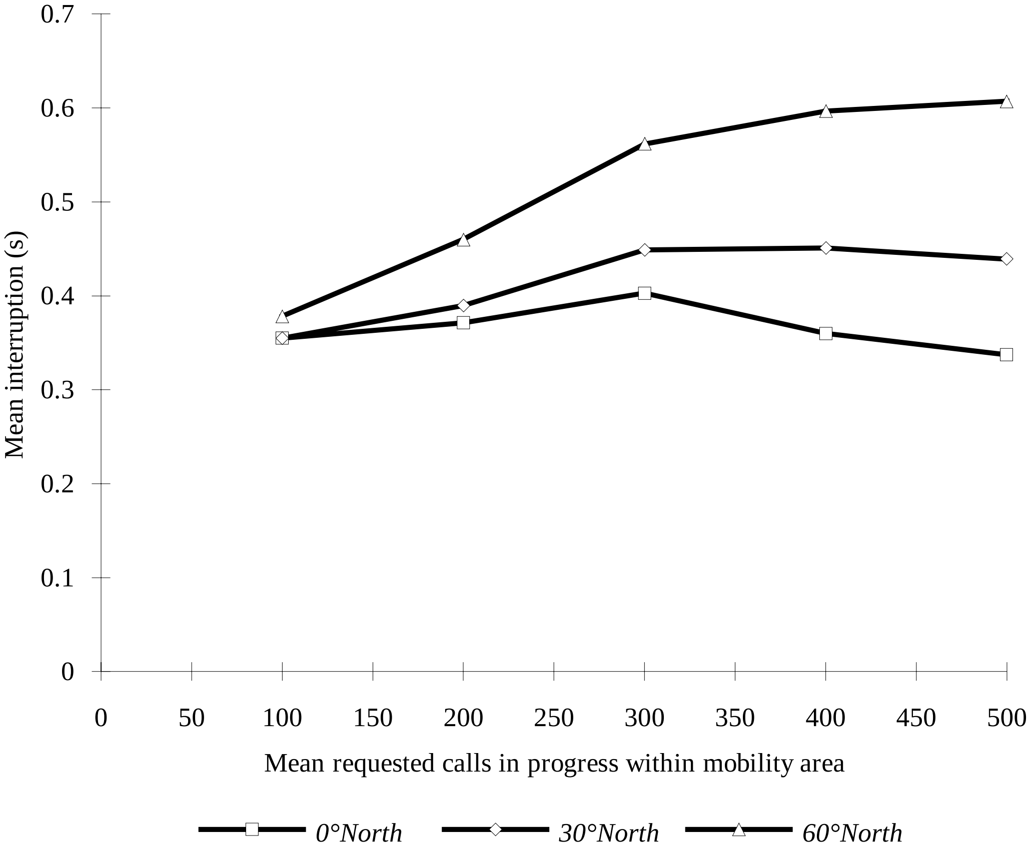

Figure B9 Mean interruption at intra-satellite handover as a function of traffic intensity

Mean requested calls in progress within mobility area	0°North	30°North	60°North
100	1.5	1.5	1.5
200	1.5	1.5	1.5
300	1.5	1.5	1.5
400	1.5	1.5	1.5
500	1.5	1.5	1.5

Table B1 Interruption (in seconds) at worst case intra-satellite handover events

Figure B9 shows that intra-satellite handovers execute quickly, leaving an average pause in communications of roughly half a second at operational call intensities. The pauses are slightly longer than this at higher latitudes as the number of satellites covering any given mobile terminal increases, confusing the interference pattern and making the predictions made by the FES based upon its measurements less accurate. At overload traffic intensities, intra-satellite handovers are executed faster when the traffic overload is greater. This happens because interference becomes so bad that FES measurements alone quickly establish when intra-satellite handover is unlikely to be possible, without much help from the mobile terminal. Those intra-satellite handovers that are attempted appear to be more likely to succeed rapidly. Table B1 shows the maximum interruption to be 1½s, which corresponds to the maximum of 5 channels tested.

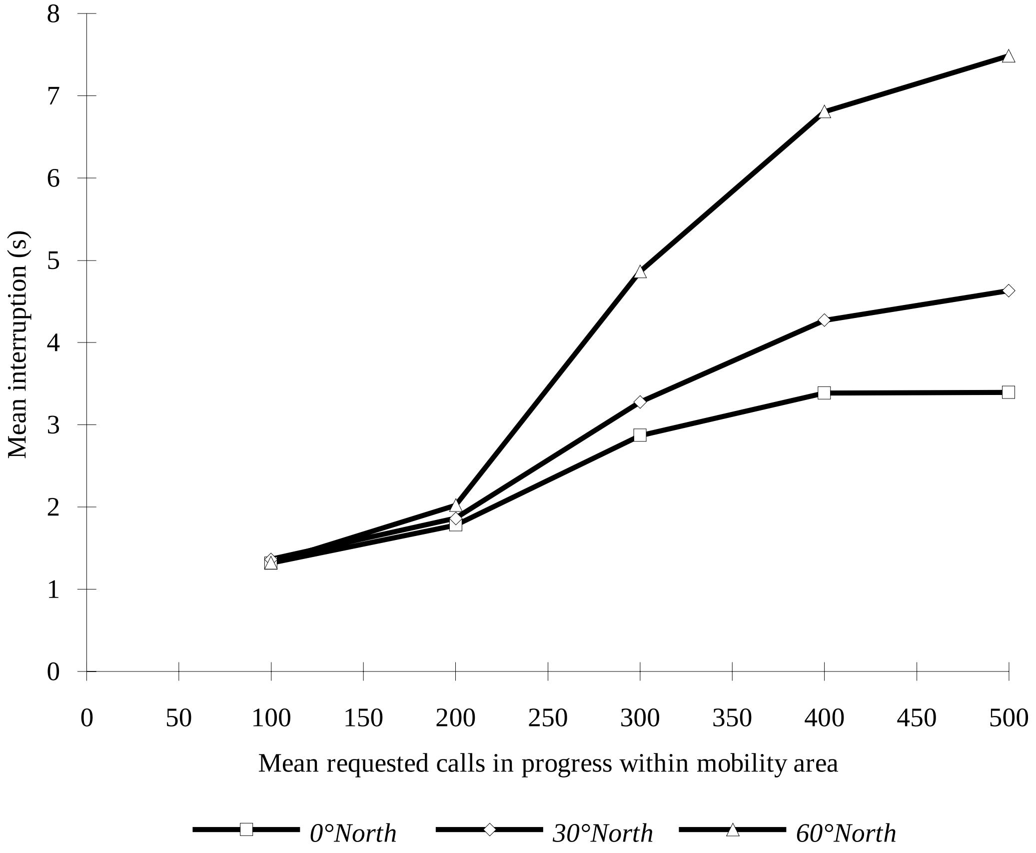

Figure B10 Mean interruption at inter-FES handover as a function of traffic intensity

Inter-satellite handover occurs only after intra-satellite handover has failed, a process which on average takes nearly 1½s (the time taken for 5 attempts at finding channels on the same satellite to have failed). In addition to this delay is the time taken to find a new channel on a different satellite that is controlled by a different FES in this simulation. Figure B10 shows that the mean handover drop-out duration remains less than five seconds for a system loaded with a traffic intensity up to 300 calls per 69,360,000km^2. It also shows that the penalty for overloading the system is high in terms of the handover drop-out duration for the simulated system.

Mean requested calls in progress within mobility area	**0°North**	**30°North**	**60°North**
100	15.9	17	14.2
200	15.9	16.75	30.7
300	19	19.7	32.95
400	19.2	18.95	34.2
500	19.45	19.45	30.75

Table B2 Interruption (in seconds) at worst case inter-FES handover events

In the simulation no hard limit was set on the number of satellites that could be tried for an inter-satellite handover. Table B2 shows how long the maximum delay can be at inter-satellite handover, especially at higher latitudes where a mobile terminal would have more satellites to choose from. During the simulations drop-outs as long as 34.2s were recorded - it is unlikely that customers would wait this long for their communications channel to return. These statistics show the potential advantage of reducing the number of FESs and allowing FESs to use multiple satellites. This would usually allow a FES to remain in control of the channel assignment for the whole duration of a call, which would significantly speed the process of channel assignment by minimizing the use of the mobile terminal to find a new satellite, which is where most of the delay occurs. In this simulation the terminal has to search for a new satellite paging channel without any knowledge of which satellites may be available to it. Using the UMTS Network Architecture described in chapters 5 and 6 the FES would know which satellites are most suitable for communications and would be able to execute the inter-satellite handover more rapidly.