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Re:	SDD Session 56 Cleanup, in response to the call for PHY details: "Any parts of Section 11 (PHY) that are incomplete, inconsistent, empty, TBD, or FFS."
Abstract	The contribution suggests applications for and proposes a common feedback channel for 802.16m E-MBS
Purpose	To be discussed and adopted by TGm
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Applications of Common Feedback channel for 802.16m E-MBS

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1. Introduction

The Denver version of the SDD, 80216m-08/003r4 specifies that an e-MBS feedback be provided to one or more cells but doesn’t provide any details regarding the nature and application of the feedback or how it may be provided without excessive overhead.

> **11.9.1.6 E-MBS feedback** <Editors’ Notes : This section is a placeholder for text to be developed based on SDD text that will be added to Section 15 of the SDD (Support for Enhanced Multicast Broadcast Service). >

E-MBS feedback provides information for DL MBS transmission to one or multiple cells. Details are TBD.

This contribution outlines potential feedback mechanisms that are based on common channel and their application in the context of 802.16m E-MBS and proposes text changes to the SDD. These mechanisms can drastically reduce the feedback requirements, especially for a large number of subscribers, at the expense of an imprecise but sufficiently accurate estimate.
A similar concept has been introduced in [5].

2. Applications

We now describe several applications that are currently not enabled economically for E-MBS.

A) Low overhead HARQ ACK/NAK for E-MBS

802.16m E-MBS will likely (for maximum battery efficiency) be composed of short, wideband packets that are repeated sufficiently for most of the MS to receive them. In order to minimize the number of repetitions, it is desirable to have a HARQ ACK/NAK feedback channel to indicate to the BS if a retransmission is necessary. Gains can be achieved if the number of subscribers for each downlink channel (“service”) is low but greater than one (typically 2-6 subscribers). On the other hand providing this feedback channel for every MS requires a large overhead. That overhead grows if an MS is to return feedback to multiple BS's.
On the other hand it is understood that for this application the base station (or network in general) doesn’t need to know which of the subscribers has or hasn’t received the packet only that they did. Therefore it is sufficient for this case to establish a common channel that is capable of carrying one bit of information per MS. An MS that hasn’t received the packet will send a NACK. It is also necessary that the nature of the channel be such that multiple NACK’s are interpreted by the BS as “one or more NACK’s”.
The procedure for the case where an MS combines data from two or more BSs depends on the nature of the combining, i.e. transparent to the MS or not, and is up to setup by the network. Thus the MS may report success of reception from each data source individually or the success of the combined reception.

B) Estimating the success of data delivery

In order to correctly determine E-MBS transmission parameters (coding / modulation / power), the network needs to make sure that service is available to at least a certain percentage of MSs in the cell. To ensure this, it needs to have an estimate of the total number of MSs attempting to receive the service and how many of these are receiving it successfully. To do so, 2 counts are needed for any

2 of the following 3 quantities: the number of successful receptions (ACKs), the number of failures (NACKs) and the number of MSs present (counting). This can be accomplished for example by defining separate common channels for this service for ACKs and for counting.

The reporting interval should be configured by the network and generally depend on the channel coherent time and any potential error protection mechanism at the network layer. Time averaging for each MS could be accomplished e.g. by specifying that NACK is transmitted if a certain fraction of received packets is in error.

As for the HARQ feedback, it is not necessary for the network to know who has had errors, only what percentage of the total.

Unlike application A, in this case the number of subscribers could be very large. Overhead for this case can be reduced by assigning a probability to transmit. Note that the probability to transmit needn't be the same for NACK and counting.

Similar to the HARQ ACK/NAK case, the MS may report individual success per data stream if that information is available to it and if configured to do so.

C) Estimating number of subscribers

In some applications a broadcast service transmits certain contents to users. How are certain users enabled to receive a specific content, or channel, is beyond the scope of this contribution. The broadcaster may however need to estimate how many users are listening to the channel, for example in order to enable him to estimate how much to charge advertisers whose contents is also broadcast on same channel. Note that similarly to B, it is not important to know who those listeners are, only how many of them. To this effect the listeners are instructed to send a signal (counting) with priority *p*.

3. Mechanisms

3.1 The common channel

The proposed common access channel therefore must have the following properties:

- It carries a single pre-assigned payload bit
- If two or more MSs access it at the same time, the BS will interpret it as "one or more".

3.2 The procedure

The procedure varies between application "A" (HARQ feedback) and counting applications ("B", "C").

A) Procedure for Application – A (HARQ feedback)

For each service we define one common channel as described above and the MS is notified of it. (It is possible to use more but not necessary). Then for every failed packet, the MS will transmit NACK. The BS, upon detecting a NACK, may retransmit the packet per the usual HARQ procedure until a maximum number of retransmissions is reached.

B) Procedure for Application – B ("Counting")

As seen above, for both applications "B" and "C" we would need a counting procedure that is able to count a large number of events. A stochastic counting is used, that is the base station will generate an estimate of the number of events, rather than an actual deterministic count. The accuracy of the estimate can be made to be as high as we require by controlling the access parameters and by time or cell averaging, depending on the application.

- We allocate a set of N channels ($N < M_{\max}$) which the MSs access at random. We then count the number of channels used and estimate M. While our estimate is not precise, we demonstrate that the error is tolerable for many applications (see appendix). The counting error depends on the number of channels and the number of MSs.
    - A suitable number of channels N that is needed for acceptable error is obtained by solving for N the following:

$$M_{\max} = \frac{c}{p} N \ln(N) \qquad (1)$$

where c is some tolerance factor (which we set at 2) and p is the probability with which an MS transmits if the conditions for transmission are met. Setting c=2 appears to be sufficient. For large $M_{\max}$, N can be significantly lower then $M_{\max}$ resulting in substantial reduction in signaling overhead in the uplink.

A generic procedure can be defined in the following manner. With each procedure there is an associated “transmission event” (TC) defined. An event may be one of the following:

- Reception of a particular command to “count”
- A timer
- Failure to receive a particular transmission after a specified number of times (which could be one).
- Failure to receive a particular transmission more than a certain percentage of the time.

These events may be standardized, broadcast or signaled to specific MSs.

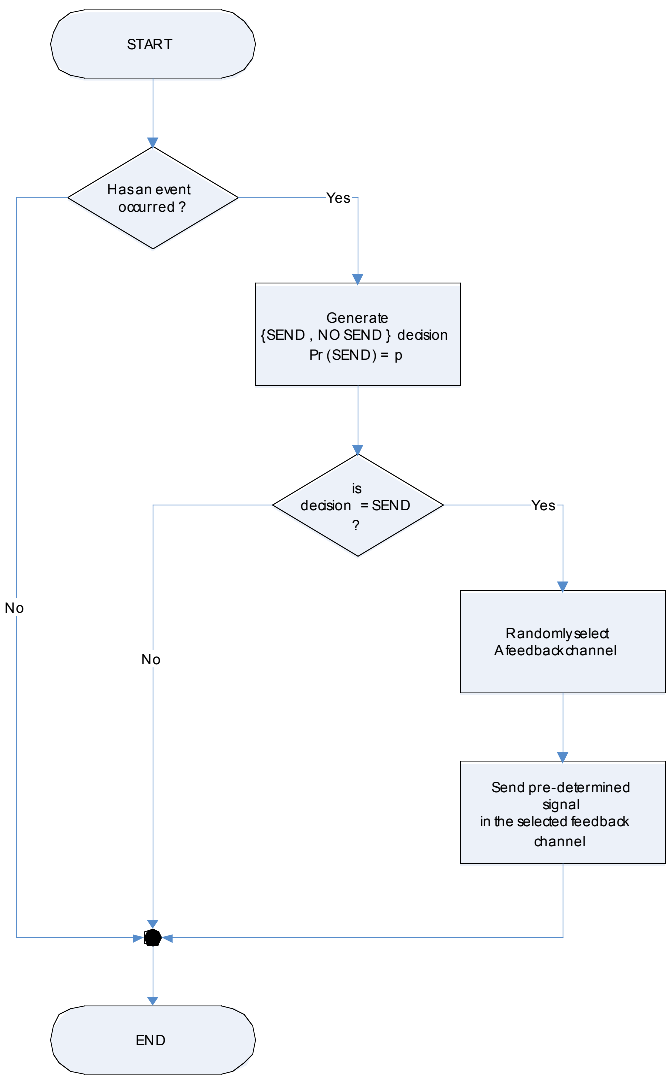

Figure 1. MS per P-FRACH decision flowchart

The MS decides whether to send a feedback and in what channel to send using the flowchart in Figure 1. As shown in Figure 1, when an MS satisfies the transmission event (i.e. answers “YES”), it randomly chooses one of N available access channels. It then transmits a pre-defined signal on this channel with probability p>0. Otherwise, the MS does nothing. All MSs transmit the same signals and the signals are to be designed in such a way that collisions are unlikely to result in nulling of a signal.

The BS estimates whether each channel was used (typically using a signal detection scheme). It counts their number and estimates the number of MSs which have accessed it. An approximate estimator that can be used is

$$\widehat{M}(t) = -\frac{N}{p}\ln\left(1-\frac{t}{N}\right) \qquad (2)$$

Where N is the total number of channels provided and t is the number of channels that has been accessed.

4. Discussion

The estimator in (2) is simple and has a low bias (see appendix) for large *N* and *t*. A more accurate estimator can be obtained by numerically solving A.2 to maximize *Pr{T=t}*.

Note that the highest number of transmitting MS that estimator will estimate is $N\ln(N)$. The useful range of the estimator is somewhat lower, perhaps 20-30% lower. Keeping the number of actually transmitting MSs to this limit will result in errors not significantly exceeding ±30%. This error should be acceptable for purposes of estimating QoS.

In spite of its limitations, the scheme is very useful in those cases where the number of MSs transmitting on any single common channel set is not known but the system has some flexibility in allocating the number of channels in the set. This is due to the fact that while a high number of MSs cannot be estimated accurately, it still registers as “too high” enabling a coarse network parameter adjustment. Thus for example if a common channel set is provided for a QoS feedback (NACK) for a service, and almost all channels in it are used, the network should provide more downlink resources for this channel. Thus the actual number of MS that could be supported is much higher.

5. Text Proposals

11.9.1.6 E-MBS feedback <Editors' Notes : This section is a placeholder for text to be developed based on SDD text that will be added to Section 15 of the SDD (Support for Enhanced Multicast Broadcast Service). >

E-MBS feedback provides information for DL MBS transmission to one or multiple cells. Details are TBD.

11.9.1.6.1 Failure feedback for E-MBS

The BS may schedule the transmission of NAK information, i.e. a transmission would occur if and only if certain pre-defined failure conditions are met, otherwise nothing is transmitted. A NAK is transmitted in a randomly selected E-MBS common feedback channel out of a set of common feedback channels signaled by the BS. *Informative text: for HARQ application the set consists of a single channel.*

NAK can be configured to be transmitted with a probability *p* per each failure of the downlink packet, or after a pre-defined number of failures in a pre-defined number of transmissions. The probability *p* will be signaled by the BS. The probability could be defined per feedback type.

The BS may assign more than a single set of common channels per E-MBS service to separately indicate failure of several streams of data that belong to that service.

11.9.1.6.2 Counting feedback for E-MBS

The BS may schedule the transmission of counting feedback. Counting feedback is transmitted in a randomly selected an E-MBS common feedback channel out of a set of common feedback channels signaled by the BS.

Counting feedback can be configured to be transmitted with a probability *p*. The probability *p* will be signaled by the BS.

11.9.1.6.3 E-MBS common feedback channel

Editorial note: this text could be placed either in an E-MBS section following the above or in the uplink control section

Exact details of the common feedback channel definition are FFS. The text below is brought for illustrative purposes only.

An E-MBS common Feedback Channel could be defined by the BS as follows. A group of sub-carriers (for example a resource block or a part of a resource block) is designated by the BS. A set of L_s mutually orthogonal signatures whose length L_s matches the number of sub-carriers is defined. There are N_G groups of sub-carriers defined as above. An E-MBS common Feedback channel is then defined as one signature over one sub-carrier group. An example is given below (for length 16) which shows that 6 sets of 16 signatures can fit in an 19x6 resource block for a total of 96 common access channels.

P	S_1	S_1	P	S_1	S_1
P	S_1	S_1	P	S_1	S_1
S_1	S_1	S_1	S_1	U	U
S_1	S_1	S_1	S_1	U	U

S_2	S_2	S_2	S_2	S_3	S_3
S_2	S_2	S_2	S_2	S_3	S_3
S_2	S_2	S_2	S_2	S_3	S_3
S_2	S_2	S_2	S_2	S_3	S_3
S_3	S_3	P	S_3	S_3	P
S_3	S_3	P	S_3	S_3	P
S_4	S_4	S_4	S_4	S_4	S_4
S_4	S_4	S_4	S_4	S_4	S_4
S_4	S_4	S_4	S_4	U	U
S_5	S_5	S_5	S_5	S_5	S_5
S_5	S_5	S_5	S_5	S_5	S_5
S_6	S_6	S_6	S_6	S_6	S_6
S_6	S_6	S_6	S_6	S_6	S_6
U	P	S_6	S_6	P	U
U	P	S_5	S_6	P	U

Figure 2: Example of common E-MBS channel. “P” and “U” are pilot and unused sub-carriers respectively.

Sequence sets S_i, $i=1,.., N_G$ consist of V_j $j=1,\ldots, L_s$ mutually orthogonal vectors of length L_s each, derived for example by using a Hadamard matrix.

The groups are then arranged consecutively as

$C_i = \{V_1(S_1), V_2(S_1), \ldots, V_{Ls}(S_1), \ldots, V_1(S_2), V_2(S_2), \ldots, V_{Ls}(S_2), \ldots, V_1(S_{NG}), V_2(S_{NG}), \ldots, V_{Ls}(S_{NG})\}$

Where C_i defines a common channel.

A set of $N_{EMBS\_common\_Feedback}$ common channels is signaled to the MS to be used for ACK/NAK and counting feedback.

References

[1] B. Dawkins, “Siobhan’s Problem: The Coupon Collector Revisited,” *The American Statistician*, vol. 45, no. 1, pp. 76-82, Feb. 1991.
[2] R. P. Stanley, *Enumerative Combinatorics, Vol. 1*, Cambridge U. Press, Cambridge, UK, 1997.
[3] E. W. Weisstein, “Stirling Number of the Second Kind,” *Mathworld* – a Wolfram Web Resource. http://mathworld.wolfram.com/StirlingNumberoftheSecondKind.html.
[4] Deleted
[5] C80216m-08_275 “IEEE 802.16m UL Common Feedback”
[6] 80216m-08/003r4, 802.16m SDD

6. Appendix: Analysis of the counting function

1. Estimation of M: general approach

Assuming MSs transmit with a known probability *p* we need to estimate the total number of MSs *M*. A simple way to approach estimation of *M* is to think in terms of MSs that "should be transmitting" (this is *M*) and those among these MS that actually did transmit – we denote these by $\widetilde{M}$ (which could be specifically known or estimated). Let us suppose we know $\widetilde{M}$, then a simple and good estimate of *M* based on $\widetilde{M}$ is as follows:

$$\hat{M}(\widetilde{M}) = \frac{1}{p}\widetilde{M} \qquad \text{(A.1)}$$

2. An Estimator for *M* with *p*=1

Let *T* be the number of used channels out of a total of *N* channels. Thus, *T* is a random variable and $0 \le T \le N$. Based on this, we would like to be able to estimate the number of mobiles that actually transmitted.

To do so, we start with the distribution of *T* given *M*. This is the distribution that when *M* agents picked one of *N≥1* objects (with replacement), only *T* distinct objects are actually picked. The problem is closely related to the *coupon collector* problem – a standard combinatorial problem. The exact distribution is given by (see [1] and references therein)

$$\begin{aligned} &\Pr\{T = t\} = \frac{N!}{(N-t)!}\frac{S(M,t)}{N^M}, \quad 0 \le t \le \min(N,M) \\ &\Pr\{T = t\} = 0 \qquad\qquad \text{otherwise} \end{aligned} \qquad \text{(A.2)}$$

where *S(M,T)* is the Stirling number of the 2nd kind defined as ([2,3])

$$S(M,t) = \frac{1}{t!}\sum_{j=0}^{t}(-1)^j\binom{t}{j}(t-j)^M \qquad \text{(A.3)}$$

We note that the distribution is quite complex, which will make the task of exact analysis difficult. In particular, the maximum likelihood (ML) estimate is difficult to obtain as maximizing (A.2) over *M* is difficult analytically.

Instead, we take a different approach. It is well known from combinatorial literature that asymptotically

$$E[T] \sim N(1 - e^{-M/N}) \qquad \text{(A.4)}$$

While the expression above is accurate only asymptotically, it turns out to be good enough. From (A.4) we propose the following estimator:

$$\widehat{M}(t) = -N\ln\left(1 - \frac{t}{N}\right) \qquad \text{(A.5)}$$

Note that if *t=N*, the estimate $\widehat{M}(N) = \infty$. This makes intuitive sense in the view of an ML estimation – maximizing *a posteriori* likelihood. Suppose that all channels have been used. What is the number of MSs that makes it most likely that this would happen? The answer is the more MSs the more likely that all channels are used up – so, absent any upper bound, the intuitively correct estimate on the number of MSs should be infinite.

Using this intuition we can suggest a design criteria for selecting an appropriate number of feedback channels, given a maximum expected number of MSs. Specifically, we set

$$M_{\max}(N) = -cN\ln\left(1-\frac{N-1}{N}\right) = cN\ln(N) \qquad \text{(A.6)}$$

which can be solved for N numerically given an $M_{\max}$. Equation (1) is then obtained by combining (A.6) with (A.1). Here c is some appropriately selected constant, which can even be set greater then 1 but not too much so. A reasonable choice of c is to set c=2, which we will use throughout.

The resulting $\widehat{M}(t)$ for various values of N are shown in figures below. The same figures show a scatter plot of randomly selected values of M and the resulting observed values of T. In all these figures N is fixed. For each iteration a value of M is selected at random between 1 and a maximum value $M_{\max}$, which is found from 5 with c = 2. For each such value, a value of t generated by randomly selecting one of $\{1, \ldots, N\}$ M times and adding up the number of values selected. Each figure shows a scatter plot of actual realizations of $M(t)$ as well as the estimate $\widehat{M}(t)$ as a solid line. For each plot, we also demonstrate a second figure, where the values of $M(t)$ have been normalized by $\widehat{M}(t)$. This demonstrates how far the actual value of M is likely to be from the estimate. 10,000 iterations are used, except for N = 100, where 100,000 iterations are required as $M_{\max}$ ~ 1000.

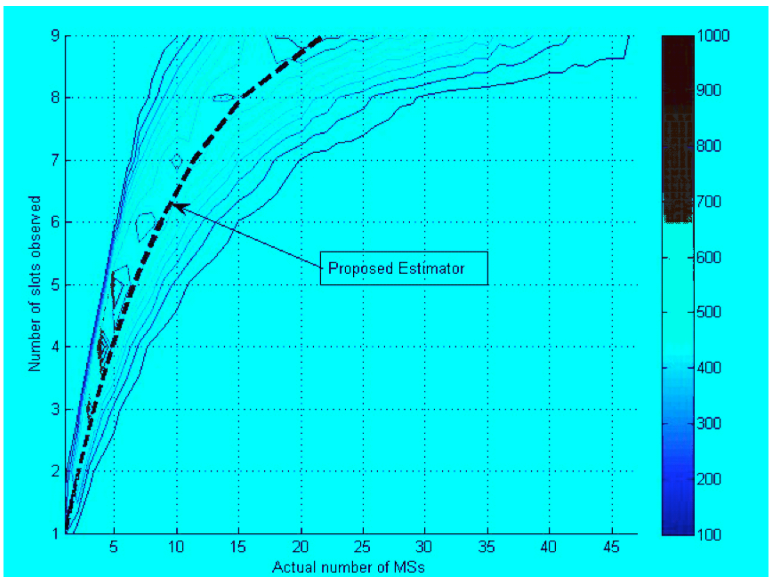

Figure A-1. Contour and Estimate. N=10

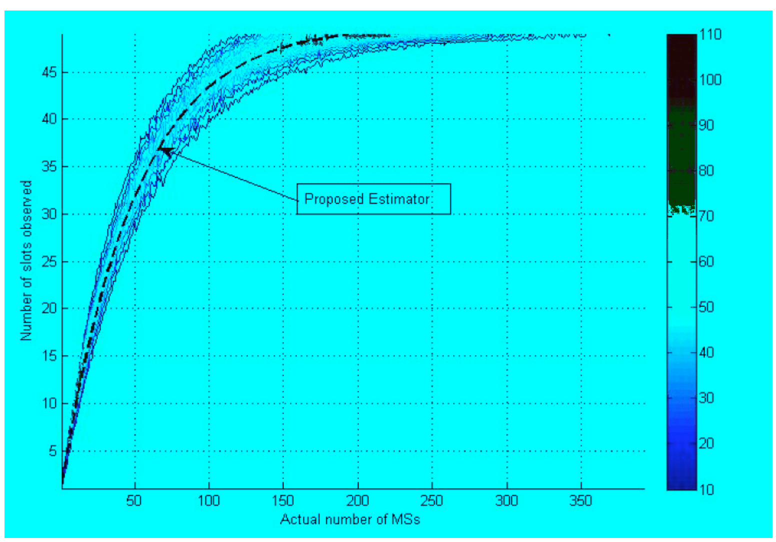

Figure A-2. Contour and Estimate. N=50

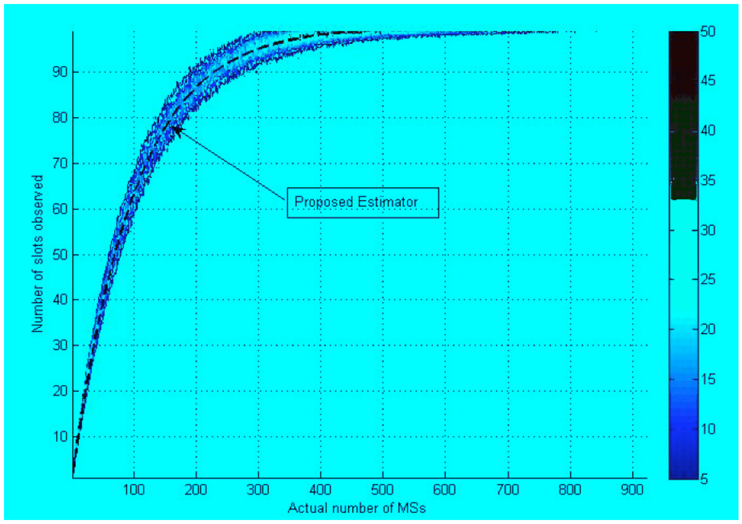

Figure A-3. Contour and Estimate. N=100

The real power of this approach comes through when we set p<1. We illustrate this by using a very low value p=0.01. Keeping c=2, we can then support 4606 MSs with N=10, 39121 MSs with N=50 and 92104 (amost 100,000) MSs with N=100. Because the estimator now involves two independent estimation steps ((A.6) followed by (A.1)), one expects the variance of the actual value of M around the estimate to grow. However, as we illustrate in Figures 8 – 10, except when t is close to 0 or close to N, this growth is very moderate. Our error remains just about a factor of 3, except for the very low value of N=10.

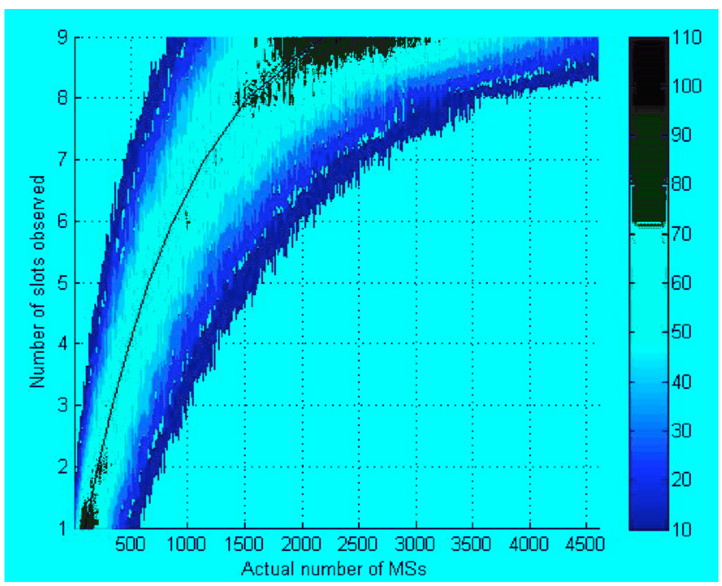

Figure A-4. Contour and Estimate. $p=0.01$, N=10

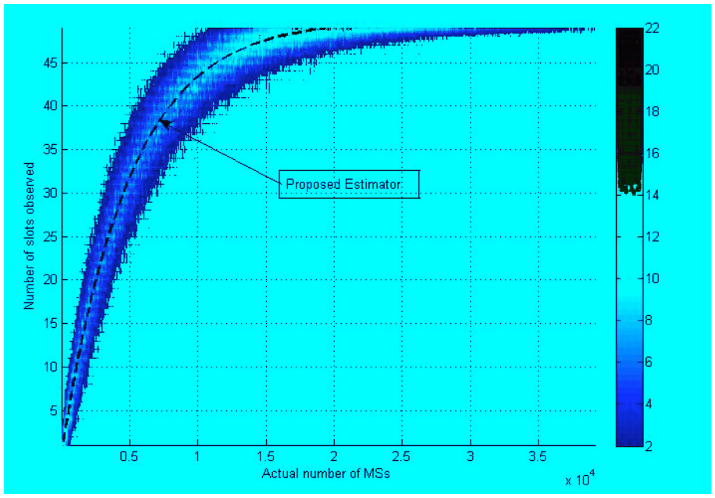

Figure A-5. Contour and Estimate. *p=0.01, N*=50

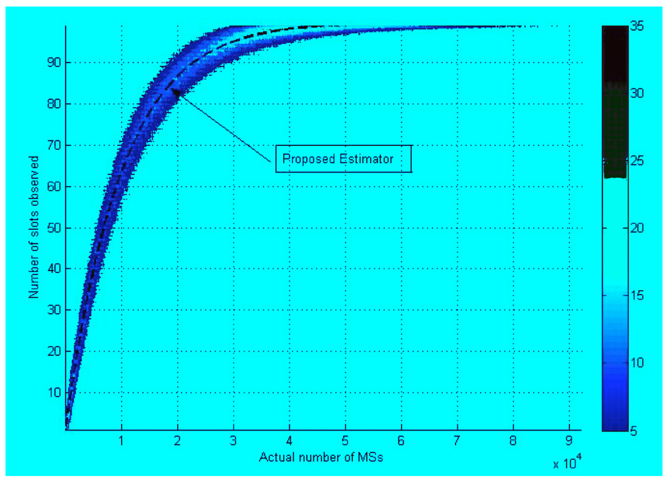

Figure A-6. Contour and Estimate. *p=0.01, N*=100