ALMA Memo No. 277
Sensitivity Loss versus Duration of Reconfiguration and ALMA Array Design

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Abstract

The analysis of effective time loss during reconfiguration by Guilloteau (1999) is re-examined for the robustness of his conclusion that the time loss is minimized by moving only a small number of antennas each day. I am able to reproduce this analysis and found that this conclusion is independent of the assumptions on antenna move time and the length of post-move calibration. I find, however, this optimization to compete against the total duration for reconfiguration, which is a serious concern for the reconfiguration to and from the largest configuration. A more fundamental problem is that this concern over reconfiguration efficiency is dwarfed by the concern over observing efficiency in most cases, as previously shown by the cost-benefit analysis by Holdaway (1998) and by Yun & Kogan (1999). A stronger case will be made if such a gradual reconfiguration scheme can be shown to achieve a high observing efficiency as well.

1 Introduction

Sensitivity loss resulting from configuration changes has been formulated and computed by Guilloteau (1999) in terms of equivalent integration time lost. His conclusion that moving the fewest possible antennas each day is optimum for minimizing the equivalent integration time loss is both surprising and counter-intuitive. The robustness of this conclusion is tested by examining the assumptions entered into the calculations. Other relevant issues that may impact this analysis are also considered.

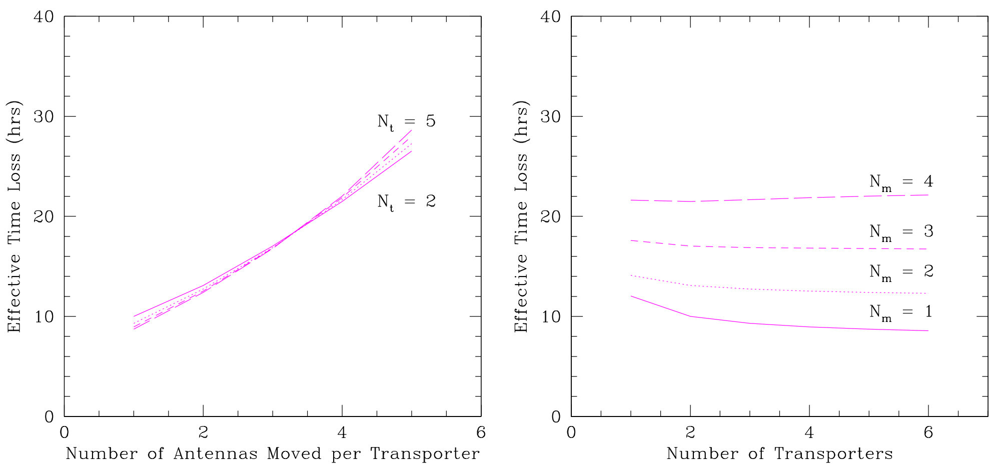

Figure 1: Equivalent integration time loss for one complete reconfiguration, computed using Eq. 8 of Guilloteau (1999), is plotted as a function of the number of transporters (right) and as a function of the number of antennas moved per transporter per day (left).

2 Formulation of the Problem

When N antennas are moved each day (N_m antennas by each of the N_t transporters), N antennas are not available for observing during the period lasting $N_m \times t_m$ hours (t_m is antenna move time). In addition, at least $N+1$ antennas are unavailable for astronomical observations during the post-move calibration time of t_{cal} hours. The resulting sensitivity loss can be computed in a straightforward way, and Guilloteau (1999) quantifies this in term of "the effective time loss due to reconfiguration", i.e. the time required to obtain the same sensitivity with the full array (see Eqs. 3-8 in Guilloteau 1999).

The resulting time loss is shown as a function of number of transporters and the numbers of antennas moved per transporter in Figure 1. Since it makes no sense to move fewer antennas than the number of transporters available, N_m is defined slightly differently here as *the number of antennas moved per day per transporter*. What is actually shown is that the effective time loss is minimized by moving only one antenna per day per transporter ($N_m = 1$), *independent of the number of transporters used.* If no other considerations are included, having more than 2 transporters[1] does not produce any significant additional gain, and this led Guilloteau to conclude that "it is preferable to move a small number of antennas and re-calibrate their postings and pointing constants every day." This surprising and seemingly counter-intuitive result is further accentuated by casting the sensitivity loss in terms of *time loss*, which scales as the *square of the number of antennas* affected. For this reason, moving the fewest possible antennas per day may indeed represent the optimum case despite the much longer reconfiguration period required.

3 Duration of the Reconfiguration

An important missing consideration in this analysis is the duration of the reconfiguration. By minimizing only the effective time loss, the apparent optimum solution has been driven toward the maximum reconfiguration duration. In fact, the elementary and the most optimum solution, in terms of minimum sensitivity loss, is actually "no reconfiguration". However this trivial solution is ruled out implicitly because it would also take an infinite amount of time to reconfigure. While absurd in nature, this solution highlights the need for including a consideration for a total reconfiguration duration.

Particularly concerning is the reconfiguration into and out of the largest configuration. As discussed briefly in MMA Memo 265 (Yun & Kogan 1999), a reasonable estimate for an antenna move should be closer to 3 hrs each in this case rather than 2 hrs. Since any 10 km diameter or larger configuration must circle Cerro Chascon and be detached from the other configurations, and since the jump in baseline is so large, probably little science can be done during this reconfiguration. Therefore minimizing the reconfiguration duration, either by increasing the number of transporters or by limiting the frequency of this longest configuration, is highly desirable. Otherwise, the effective time loss due to this reconfiguration will add up to several 100's of hours, rather than just few 10's of hrs – a full reconfiguration would take 32 days if 2 antennas are moved each day (versus 8 days total if 4 transporters are used to move 2 antennas each or 4 days if a "new" configuration can be achieved by moving only 1/2 of the antennas – see Kogan 1998). A proposed

[1] Having a minimum of two transporters is probably prudent to anticipate occational break downs of one or more transporters.

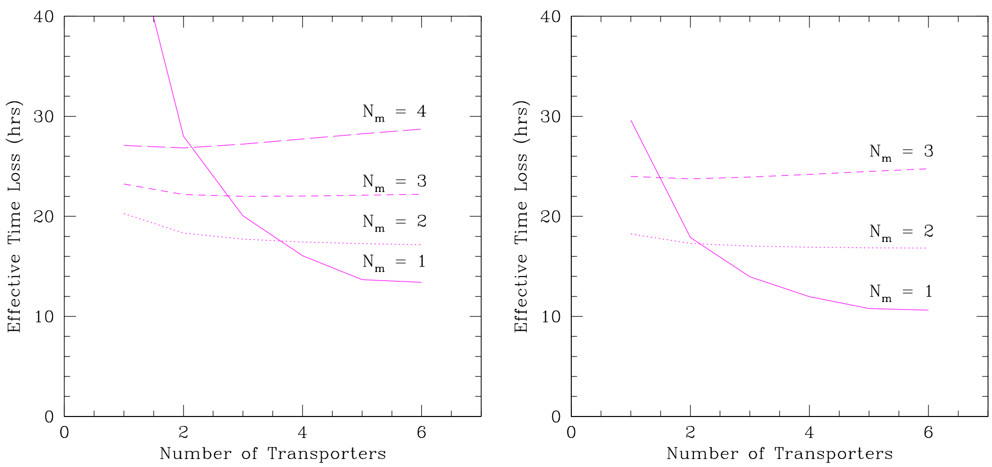

Figure 2: Equivalent integration time loss for one complete reconfiguration as computed in Fig 1 but for increasing average antenna move time from 2 hrs to 3 hrs (right) and for increasing the calibration time from 2 hrs to 4 hrs (left). When an additional constraint of 6 minimum antennas for post-move calibration is introduced, $N_m = 1$ case no longer offers the optimum strategy as before.

reconfiguration schedule and a more detailed estimate for the reconfiguration time will be discussed in a memo by S. Radford (in preparation).

4 Testing the Assumptions

Continuing with the arguments offered by Guilloteau (1999) for the moment, I examine the robustness of his conclusion that making fewer moves per day using only one or two transporters is optimal. In particular, assumptions on the time required for moving antennas and post-move calibrations are tested.

It should be noted that the increase in point source sensitivity achieved by using larger antennas and greater numbers of elements does not necessarily shorten the duration of the baseline measurements because scatter in the measured phase is dominated by the atmospheric term rather than by thermal noise – the power spectrum of the atmospheric phase fluctuation measured at Owens Valley by Lay (1997) suggests that integrations as long as 5 minutes may be needed to remove more than 90% of the atmospheric contribution.[2] As shown in Figure 2, increasing the post-move calibration time from 2 hrs to 4 hrs actually makes the situation worse, in terms of the effective time loss, as does the increase in the antenna move time from 2 hrs to 3 hrs. Thus neither change affects Guilloteau's key conclusion that moving the fewest possible antennas is optimum in minimizing the effective time loss. This is no longer surprising since these changes only compound the existing time losses during reconfiguration.

One significant new development in the analysis occurs when a minimum on the number of antennas is imposed for the post-move calibration. In general, at least three antennas are needed for baseline and pointing calibration for phase closure. Also, the speed (sensitivity) of the interferometric pointing measurements scales roughly as the numbers of antennas used. In addition to having at least one "good" antenna for bootstrapping the baseline solution with the rest of the array, these considerations favor using at least 5-6 antennas for the post-move calibrations. When this additional constrain is introduced, the $N_m = 1$ case no longer represents a simple set of optimum solutions as before. Furthermore, Figure 2 suggests that having only 1-2 transporters can actually result in a severe increase in the integration time loss if the post-move calibration can take up to 4 hrs, and the optimum number of transporters should be closer to 4 or 5 now. The $N_m = 2$ case with fewer number of transporters may represent a reasonable compromise, and this new analysis now generally favors having at least 3-4 transporters in total. Having a larger number of transporters also addresses the concern over the rapid reconfiguration in and out of the largest array (see §3). It should also be noted that there will be additional demands for the transporters as one or more transporters will be needed for transporting antennas from San Pedro to the site quite frequenctly during the construction phase and for transporting back and forth between the site and support facility for regular maintainance and major upgrades during the operation phase.

[2] If radiometric phase correction technique can be used to reduce this contribution, the baseline calibration may proceed more quickly. However, this will require highly accurate modeling of the atmosphere.

5 Discussion and Summary

Using the same simple assumptions adopted by Guilloteau (1999), I was able to reproduce the analysis which led to his conclusion that moving the fewest possible antennas per day indeed minimizes the effective time loss due to reconfiguration. However, I also find this to compete directly with minimizing the total duration of reconfiguration, which is a serious concern for the reconfiguration to and from the largest configuration. In addition, scheduling astronomical and calibration observations under such a gradual reconfiguration scheme adds a whole new dimension of complexity and challenge to the dynamical scheduling plan.

More importantly, the cost-benefit analyses by Holdaway (1998) and Yun & Kogan (1999) have already shown that the sensitivity loss due to tapering of the data ("observing efficiency") completely dominates the loss due to reconfiguration ("reconfiguration efficiency") in most cases. These analyses directly imply that the gain in integration time achieved by moving only 1 or 2 antennas per day is relatively insignificant in absolute terms, about 5-10% at best in terms of the overall array efficiency, compared with up to 50% loss that can arise in observing efficiency. Besides, most of the gain achieved in reconfiguration efficiency may be negated by the increased total duration of the reconfiguration (see §3).

It has been stated previously (without a quantitative analysis) that a telescoping array concept with continuous reconfiguration is designed to minimize the sensitivity loss due to tapering (e.g. Conway 1998). A stronger case for a gradual reconfiguration strategy may be best made if it can be shown quantitatively that such a reconfiguration plan can indeed achieve a comparable or greater observing efficiency than having a set of fixed configurations. When a minimum antenna requirement for the post-move calibration is included, having at least 3 or 4 transporters is favored even in such a gradual reconfiguration scheme.

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