Supporting information for

Translocation of Tetrahedral DNA Nanostructures through a Solid-State Nanopore

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(1) Tetrahedral DNA nanostructures and M13 DNA sequences

The 7-bp TDNs are self-assembled by four DNA strands A7, B7, C7, and D7, each of them contains 23 bases. The 10-bp, 13-bp, and 20-bp TDNs are self-assembled by DNA stands with similar names as listed below. The 7-bp marker TDNs are self-assembled by four DNA strands A7, B7, C7, and D'7. The 13-bp marker TDNs are self-assembled by A13, B13, C13, D'13. The linear DNA molecule used in our experiment is M13mp18. The sequence of one of its strands is listed below. The marker TDN is bonded to this strand. The same color indicates the pairing sequences.

strand	sequence
A7	CTCCACAAGTTCACCACTCGCAA
B7	TGTGGAGACGGTGTGAGCGGATT
C7	GTGTCAGAGGTGAACAAATCCGC
D7	CTGACACACACACCGATTGCGAG
D’7	CTGACACACACACCGATTGCGAGCGGATGAGTTATAGTATTGC
A10	TAGCTCGCTAAATTACCGCTTACGCCATAGTA
B10	CAACTCCAGGAAAGCGGTAATAGGTCCAATCT
C10	CCTGGAGTTGTTACGTGGGAAATACTATGGCG
D10	TAGCGAGCTAATTCCCACGTATAGATTGGACC
A13	TACGCTCCCAGGAATGATGTGACACGTATGTGATGCAGTCT
B13	TCCTGGGAGCGTAAGTCGAACGTAGTGTAGTTGAGCGAGCA
C13	CCAGTGGTCTCATAACGTGTCACATCAATGCTCGCTCAACT
D13	ATGAGACCACTGGTCACTACGTTCGACAAGACTGCATCACA
D’13	ATGAGACCACTGGTCACTACGTTCGACAAGACTGCATCACAAAACTGGTTCGTGTCCGTTCTAC
A20	CAGTTGAGACGAACATTCCTAAGTCTGAAATTTATCACCCGCCATAGTAGA

	CGTATCACCAGG
B20	GCTACACGATTCAGACTTAGGAATGTTCGACATGCGAGGGTCCAATACCGA CGATTACAGCTT
C20	GTGATAAAACGTGTAGCAAGCTGTAATCGACGGGAAGAGCATGCCCATCC ACTACTATGGCGG
D20	CTCGCATGACTCAACTGCCTGGTGATACGAGGATGGGCATGCTCTTCCCGA CGGTATTGGACC
M13	TCTAGAGTCGACCTGCAGGCATGCAAGCTTGGCACTGGCCGTCGT TTTACAACGTCGTGACTGGGAAAACCCTGGCGTTACCCAACTTAA TCGCCTTGCAGCACATCCCCCTTTCGCCAGCTGGCGTAATAGCGA AGAGGCCCGCACCGATCGCCCTTCCCAACAGTTGCGCAGCCTGA ATGGCGAATGGCGCTTTGCCTGGTTTCCGGCACCAGAAGCGGTGC CGGAAAGCTGGCTGGAGTGCGATCTTCCTGAGGCCGATACGGTC GTCGTCCCCTCAAACTGGCAGATGCACGGTTACGATGCGCCCATC TACACCAACGTAACCTATCCCATTACGGTCAATCCGCCGTTTGTT CCCACGGAGAATCCGACGGGTTGTTACTCGCTCACATTTAATGTT GATGAAAGCTGGCTACAGGAAGGCCAGACGCGAATTATTTTTGA TGGCGTTCCTATTGGTTAAAAAATGAGCTGATTTAACAAAAATTT AACGCGAATTTTAACAAAATATTAACGTTTACAATTTAAATATTT GCTTATACAATCTTCCTGTTTTTGGGGCTTTTCTGATTATCAACCG GGGTACATATGATTGACATGCTAGTTTTACGATTACCGTTCATCG ATTCTCTTGTTTGCTCCAGACTCTCAGGCAATGACCTGATAGCCTT TGTAGATCTCTCAAAAATAGCTACCCTCTCCGGCATTAATTTATC AGCTAGAACGGTTGAATATCATATTGATGGTGATTTGACTGTCTC CGGCCTTTCTCACCCTTTTGAATCTTTACCTACACATTACTCAGGC ATTGCATTTAAAATATATGAGGGTTCTAAAAATTTTTATCCTTGC GTTGAAATAAAGGCTTCTCCCGCAAAAGTATTACAGGGTCATAAT GTTTTTGGTACAACCGATTTAGCTTTATGCTCTGAGGCTTTATTGC TTAATTTTGCTAATTCTTTGCCTTGCCTGTATGATTTATTGGATGT TAATGCTACTACTATTAGTAGAATTGATGCCACCTTTTCAGCTCG CGCCCCAAATGAAAATATAGCTAAACAGGTTATTGACCATTTGCG AAATGTATCTAATGGTCAAACTAAATCTACTCGTTCGCAGAATTG GGAATCAACTGTTACATGGAATGAAACTTCCAGACACCGTACTTT AGTTGCATATTTAAAACATGTTGAGCTACAGCACCAGATTCAGCA ATTAAGCTCTAAGCCATCCGCAAAAATGACCTCTTATCAAAAGG AGCAATTAAAGGTACTCTCTAATCCTGACCTGTTGGAGTTTGCTT

	CCGGTCTGGTTCGCTTTGAAGCTCGAATTAAAACGCGATATTTGA AGTCTTTCGGGCTTCCTCTTAATCTTTTTGATGCAATCCGCTTTGC TTCTGACTATAATAGTCAGGGTAAAGACCTGATTTTTGATTTATG GTCATTCTCGTTTTCTGAACTGTTTAAAGCATTTGAGGGGGATTC AATGAATATTTATGACGATTCCGCAGTATTGGACGCTATCCAGTC TAAACATTTTACTATTACCCCCTCTGGCAAAACTTCTTTTGCAAA AGCCTCTCGCTATTTTGGTTTTTATCGTCGTCTGGTAAACGAGGGT TATGATAGTGTTGCTCTTACTATGCCTCGTAATTCCTTTTGGCGTT ATGTATCTGCATTAGTTGAATGTGGTATTCCTAAATCTCAACTGA TGAATCTTTCTACCTGTAATAATGTTGTTCCGTTAGTTCGTTTTAT TAACGTAGATTTTTCTTCCCAACGTCCTGACTGGTATAATGAGCC AGTTCTTAAAATCGCATAAGGTAATTCACAATGATTAAAGTTGAA ATTAAACCATCTCAAGCCCAATTTACTACTCGTTCTGGTGTTCTCG TCAGGGCAAGCCTTATTCACTGAATGAGCAGCTTTGTTACGTTGA TTTGGGTAATGAATATCCGGTTCTTGTCAAGATTACTCTTGATGA AGGTCAGCCAGCCTATGCGCCTGGTCTGTACACCGTTCATCTGTC CTCTTTCAAAGTTGGTCAGTTCGGTTCCCTTATGATTGACCGTCTG CGCCTCGTTCCGGCTAAGTAACATGGAGCAGGTCGCGGATTTCGA CACAATTTATCAGGCGATGATACAAATCTCCGTTGTACTTTGTTT CGCGCTTGGTATAATCGCTGGGGGTCAAAGATGAGTGTTTTAGTG TATTCTTTCGCCTCTTTCGTTTTAGGTTGGTGCCTTCGTAGTGGCA TTACGTATTTTACCCGTTTAATGGAAACTTCCTCATGAAAAAGTC TTTAGTCCTCAAAGCCTCTGTAGCCGTTGCTACCCTCGTTCCGATG CTGTCTTTCGCTGCTGAGGGTGACGATCCCGCAAAAGCGGCCTTT AACTCCCTGCAAGCCTCAGCGACCGAATATATCGGTTATGCGTGG GCGATGGTTGTTGTCATTGTCGGCGCAACTATCGGTATCAAGCTG TTTAAGAAATTCACCTCGAAAGCAAGCTGATAAACCGATACAAT TAAAGGCTCCTTTTGGAGCCTTTTTTTTGGAGATTTTCAACGTGA AAAAATTATTATTCGCAATTCCTTTAGTTGTTCCTTTCTATTCTCA CTCCGCTGAAACTGTTGAAAGTTGTTTAGCAAAACCCCATACAGA AAATTCATTTACTAACGTCTGGAAAGACGACAAAACTTTAGATCG TTACGCTAACTATGAGGGTTGTCTGTGGAATGCTACAGGCGTTGT AGTTTGTACTGGTGACGAAACTCAGTGTTACGGTACATGGGTTCC TATTGGGCTTGCTATCCCTGAAAATGAGGGTGGTGGCTCTGAGGG TGGCGGTTCTGAGGGTGGCGGTTCTGAGGGTGGCGGTACTAAAC CTCCTGAGTACGGTGATACACCTATTCCGGGCTATACTTATATCA ACCCTCTCGACGGCACTTATCCGCCTGGTACTGAGCAAAACCCCG CTAATCCTAATCCTTCTCTTGAGGAGTCTCAGCCTCTTAATACTTT

	CATGTTTCAGAATAATAGGTTCCGAAATAGGCAGGGGGCATTAA CTGTTTATACGGGCACTGTTACTCAAGGCACTGACCCCGTTAAAA CTTATTACCAGTACACTCCTGTATCATCAAAAGCCATGTATGACG CTTACTGGAACGGTAAATTCAGAGACTGCGCTTTCCATTCTGGCT TTAATGAAGATCCATTCGTTTGTGAATATCAAGGCCAATCGTCTG ACCTGCCTCAACCTCCTGTCAATGCTGGCGGCGGCTCTGGTGGTG GTTCTGGTGGCGGCTCTGAGGGTGGTGGCTCTGAGGGTGGCGGTT CTGAGGGTGGCGGCTCTGAGGGAGGCGGTTCCGGTGGTGGCTCT GGTTCCGGTGATTTTGATTATGAAAAGATGGCAAACGCTAATAA GGGGGCTATGACCGAAAATGCCGATGAAAACGCGCTACAGTCTG ACGCTAAAGGCAAACTTGATTCTGTCGCTACTGATTACGGTGCTG CTATCGATGGTTTCATTGGTGACGTTTCCGGCCTTGCTAATGGTA ATGGTGCTACTGGTGATTTTGCTGGCTCTAATTCCCAAATGGCTC AAGTCGGTGACGGTGATAATTCACCTTTAATGAATAATTTCCGTC AATATTTACCTTCCCTCCCTCAATCGGTTGAATGTCGCCCTTTTGT CTTTAGCGCTGGTAAACCATATGAATTTTCTATTGATTGTGACAA AATAAACTTATTCCGTGGTGTCTTTGCGTTTCTTTTATATGTTGCC ACCTTTATGTATGTATTTTCTACGTTTGCTAACATACTGCGTAATA AGGAGTCTTAATCATGCCAGTTCTTTTGGGTATTCCGTTATTATTG CGTTTCCTCGGTTTCCTTCTGGTAACTTTGTTCGGCTATCTGCTTA CTTTTCTTAAAAAGGGCTTCGGTAAGATAGCTATTGCTATTTCATT GTTTCTTGCTCTTATTATTGGGCTTAACTCAATTCTTGTGGGTTAT CTCTCTGATATTAGCGCTCAATTACCCTCTGACTTTGTTCAGGGTG TTCAGTTAATTCTCCCGTCTAATGCGCTTCCCTGTTTTTATGTTAT TCTCTCTGTAAAGGCTGCTATTTTCATTTTTGACGTTAAACAAAA AATCGTTTCTTATTTGGATTGGGATAAATAATATGGCTGTTTATTT TGTAACTGGCAAATTAGGCTCTGGAAAGACGCTCGTTAGCGTTGG TAAGATTCAGGATAAAATTGTAGCTGGGTGCAAAATAGCAACTA ATCTTGATTTAAGGCTTCAAAACCTCCCGCAAGTCGGGAGGTTCG CTAAAACGCCTCGCGTTCTTAGAATACCGGATAAGCCTTCTATAT CTGATTTGCTTGCTATTGGGCGCGGTAATGATTCCTACGATGAAA ATAAAAACGGCTTGCTTGTTCTCGATGAGTGCGGTACTTGGTTTA ATACCCGTTCTTGGAATGATAAGGAAAGACAGCCGATTATTGATT GGTTTCTACATGCTCGTAAATTAGGATGGGATATTATTTTCTTGT TCAGGACTTATCTATTGTTGATAAACAGGCGCGTTCTGCATTAGC TGAACATGTTGTTTATTGTCGTCGTCTGGACAGAATTACTTTACCT TTTGTCGGTACTTTATATTCTCTTATTACTGGCTCGAAAATGCCTC TGCCTAAATTACATGTTGGCGTTGTTAAATATGGCGATTCTCAAT

	TAAGCCCTACTGTTGAGCGTTGGCTTTATACTGGTAAGAATTTGT ATAACGCATATGATACTAAACAGGCTTTTTCTAGTAATTATGATT CCGGTGTTTATTCTTATTTAACGCCTTATTTATCACACGGTCGGTA TTTCAAACCATTAAATTTAGGTCAGAAGATGAAATTAACTAAAAT ATATTTGAAAAAGTTTTCTCGCGTTCTTTGTCTTGCGATTGGATTT GCATCAGCATTTACATATAGTTATATAACCCAACCTAAGCCGGAG GTTAAAAAGGTAGTCTCTCAGACCTATGATTTTGATAAATTCACT ATTGACTCTTCTCAGCGTCTTAATCTAAGCTATCGCTATGTTTTCA AGGATTCTAAGGGAAAATTAATTAATAGCGACGATTTACAGAAG CAAGGTTATTCACTCACATATATTGATTTATGTACTGTTTCCATTA AAAAAGGTAATTCAAATGAAATTGTTAAATGTAATTAATTTTGTT TTCTTGATGTTTGTTTCATCATCTTCTTTTGCTCAGGTAATTGAAA TGAATAATTCGCCTCTGCGCGATTTTGTAACTTGGTATTCAAAGC AATCAGGCGAATCCGTTATTGTTTCTCCCGATGTAAAAGGTACTG TTACTGTATATTCATCTGACGTTAAACCTGAAAATCTACGCAATT TCTTTATTTCTGTTTTACGTGCTAATAATTTTGATATGGTTGGTTC AATTCCTTCCATAATTCAGAAGTATAATCCAAACAATCAGGATTA TATTGATGAATTGCCATCATCTGATAATCAGGAATATGATGATAA TTCCGCTCCTTCTGGTGGTTTCTTTGTTCCGCAAAATGATAATGTT ACTCAAACTTTTAAAATTAATAACGTTCGGGCAAAGGATTTAATA CGAGTTGTCGAATTGTTTGTAAAGTCTAATACTTCTAAATCCTCA AATGTATTATCTATTGACGGCTCTAATCTATTAGTTGTTAGTGCAC CTAAAGATATTTTAGATAACCTTCCTCAATTCCTTTCTACTGTTGA TTTGCCAACTGACCAGATATTGATTGAGGGTTTGATATTTGAGGT TCAGCAAGGTGATGCTTTAGATTTTTCATTTGCTGCTGGCTCTCAG CGTGGCACTGTTGCAGGCGGTGTTAATACTGACCGCCTCACCTCT GTTTTATCTTCTGCTGGTGGTTCGTTCGGTATTTTTAATGGCGATG TTTTAGGGCTATCAGTTCGCGCATTAAAGACTAATAGCCATTCAA AAATATTGTCTGTGCCACGTATTCTTACGCTTTCAGGTCAGAAGG GTTCTATCTCTGTTGGCCAGAATGTCCCTTTTATTACTGGTCGTGT GACTGGTGAATCTGCCAATGTAAATAATCCATTTCAGACGATTGA GCGTCAAAATGTAGGTATTTCCATGAGCGTTTTTCCTGTTGCAAT GGCTGGCGGTAATATTGTTCTGGATATTACCAGCAAGGCCGATAG TTTGAGTTCTTCTACTCAGGCAAGTGATGTTATTACTAATCAAAG AAGTATTGCTACAACGGTTAATTTGCGTGATGGACAGACTCTTTT ACTCGGTGGCCTCACTGATTATAAAAACACTTCTCAAGATTCTGG CGTACCGTTCCTGTCTAAAATCCCTTTAATCGGCCTCCTGTTTAGC TCCCGCTCTGATTCCAACGAGGAAAGCACGTTATACGTGCTCGTC

	AAAGCAACCATAGTACGCGCCCTGTAGCGGCGCATTAAGCGCGG CGGGTGTGGTGGTTACGCGCAGCGTGACCGCTACACTTGCCAGC GCCCTAGCGCCCGCTCCTTTCGCTTTCTTCCCTTCCTTTCTCGCCA CGTTCGCCGGCTTTCCCCGTCAAGCTCTAAATCGGGGGCTCCCTT TAGGGTTCCGATTTAGTGCTTTACGGCACCTCGACCCCAAAAAAC TTGATTTGGGTGATGGTTCACGTAGTGGGCCATCGCCCTGATAGA CGGTTTTTCGCCCTTTGACGTTGGAGTCCACGTTCTTTAATAGTGG ACTCTTGTTCCAAACTGGAACAACACTCAACCCTATCTCGGGCTA TTCTTTTGATTTATAAGGGATTTTGCCGATTTCGGAACCACCATCA AACAGGATTTTCGCCTGCTGGGGCAAACCAGCGTGGACCGCTTG CTGCAACTCTCTCAGGGCCAGGCGGTGAAGGGCAATCAGCTGTT GCCCGTCTCGCTGGTGAAAAGAAAAACCACCCTGGCGCCCAATA CGCAAACCGCCTCTCCCCGCGCGTTGGCCGATTCATTAATGCAGC TGGCACGACAGGTTTCCCGACTGGAAAGCGGGCAGTGAGCGCAA CGCAATTAATGTGAGTTAGCTCACTCATTAGGCACCCCAGGCTTT ACACTTTATGCTTCCGGCTCGTATGTTGTGTGGAATTGTGAGCGG ATAACAATTTCACACAGGAAACAGCTATGACCATGATTACGAAT TCGAGCTCGGTACCCGGGGATCC
7 bp-TDN primer	GCCTACTCAATATCATAACGGAATGGATCCCCGGGTACCGAGCTCG
13 -bp TDN primer	GACCAAGCACAGGCAAGATGTTTTATTGACGGAAATTATTCATTA

(2) Gel electrophoresis characterization of DNA samples:

Our TDN-marked DNA molecules were characterized using gel electrophoresis. Figure S1 shows that the migration speed of TDN-marked M13 linear DNA molecules is similar to the original linear ds-M13 molecules. No significant difference was observed in the persistence length due to the binding of the TDNs, since significant reduction in the persistence length would result in faster migration of DNA molecules in the gel.

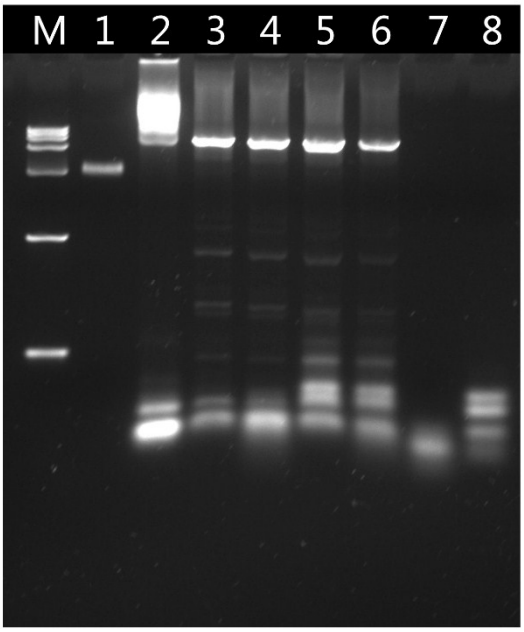

Figure S1. Gel electrophoresis characterization of DNA samples: (M) DNA ladder (DL 15000), (1) circular ss-M13, (2) circular ds-M13, (3) linear ds-M13, (4) 7-bp TDN-marked linear ds-M13, (5) 13-bp TDN-marked linear ds-M13, (6) 7-bp and 13-bp TDN-marked linear ds-M13, (7) 7-bp TDN, and (8) 13-bp TDN.

(3) Single ds-DNA (linear M13 DNA molecule) translocation statistics

Figure S2 presents the scatter plot of the current blockade versus event duration as measured for linear ds-M13, whose sequence is shown in (1). From the fitted value of $\Delta G = 0.49\ nS$, we estimate the effective thickness of the nanopore as $h = 36.8\ nm$ by using equation (1) in the main text. This value is then used to calculate the equivalent diameters of different TDNs.

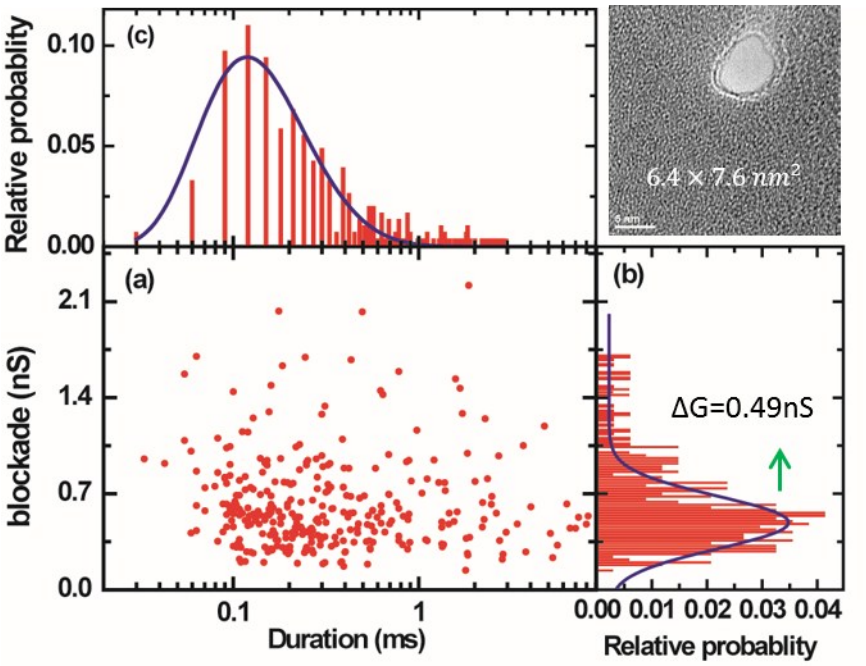

Figure S2. Translocation statistics for single linear ds-M13 DNA molecular in our experiment, total of 344 events. Inset is TEM graph of the nanopore used in this experiment.

(4) Translocation events of the third configuration

In our experiment, only two translocation events were observed for the third binding configuration with 7-bp and 13-bp TDNs attached at two sites. The detailed current traces for the two events as shown below. This low yield may stem from the poor efficiency in sample preparation.

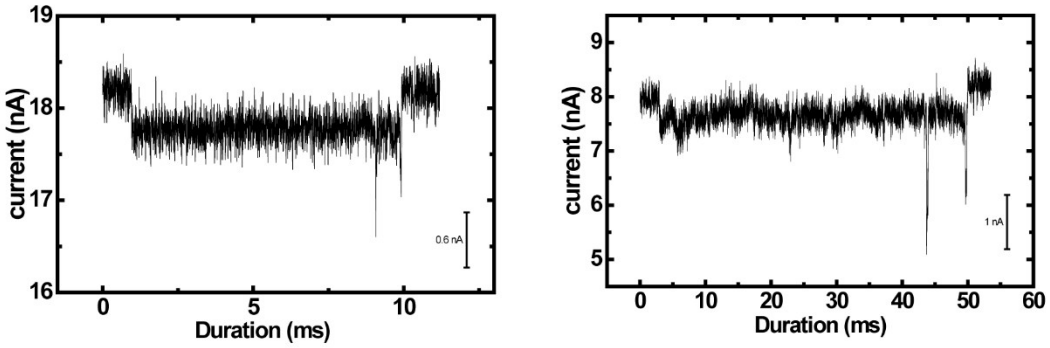

Figure S3. Translocation events for the third binding configuration as observed in our experiment.

(5) AFM characterization of TDNs-marked DNA molecules

TDNs attached to the linear M13 molecules are too small to be seen by the AFM. We attached biotin-streptavidin (STV) complex to the TDNs so that the existence and the position of TDNs can be inferred from the AFM images. The size of the biotin-STV is about 2 nm and it appears as a bright protrusion, as shown in the figures below.

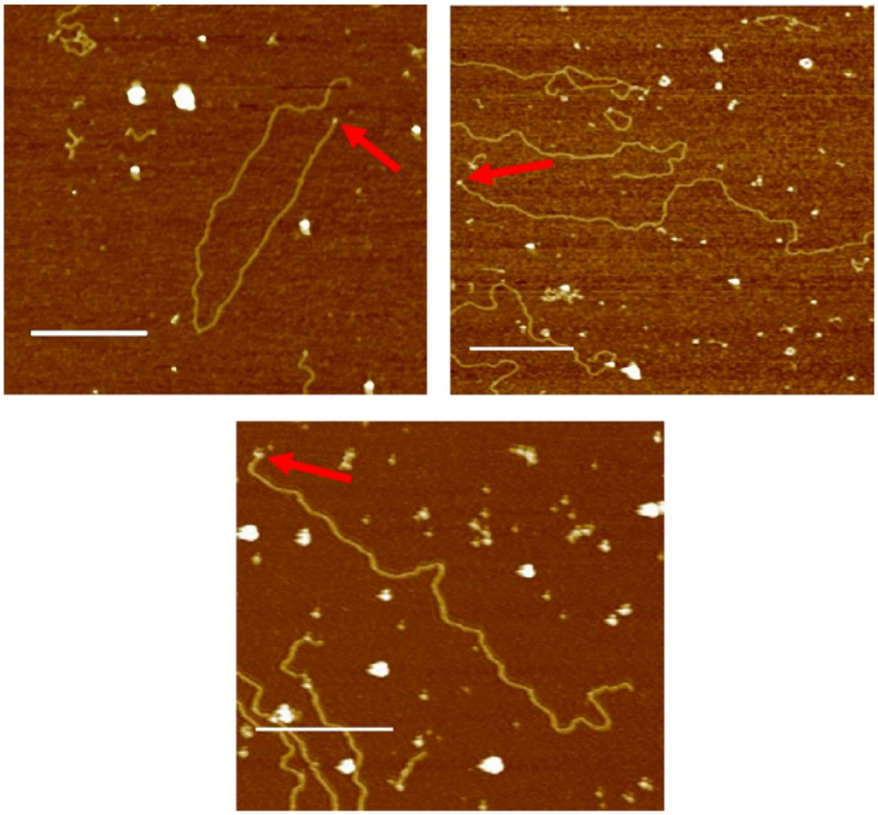

Fig S4. Typical AFM images of the TDN-marked M13 molecules for the first binding configuration. The positions of 7-bp TDNs are marked by the red arrows. Scale bars: 500 nm.

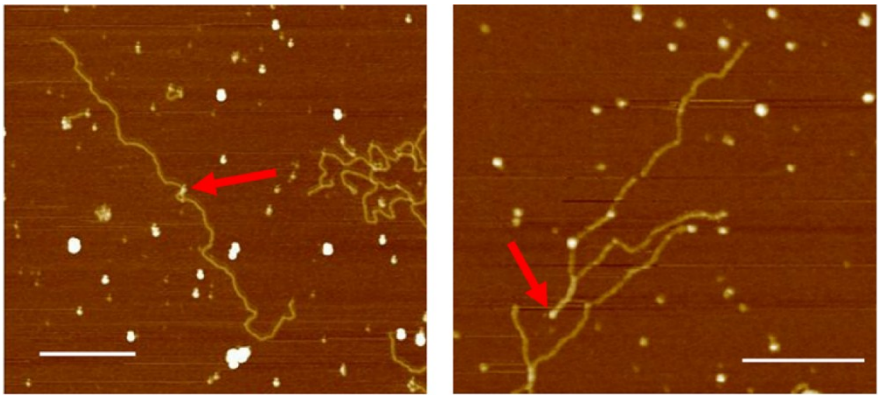

Fig S5. Typical AFM images of the TDN-marked M13 molecules for the second binding configuration. The positions of 13-bp TDNs are marked by the red arrows. Scale bars: 500 nm.

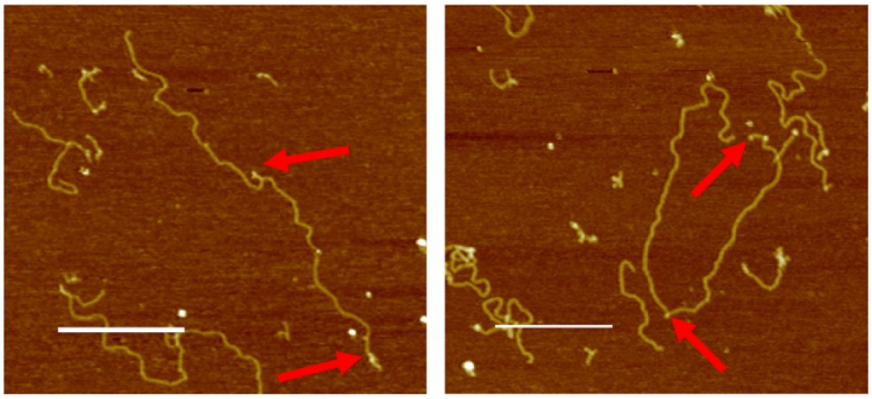

Fig S6. Typical AFM images of the TDN-marked M13 molecules for the third configuration. The positions of 7-bp and 13-bp TDNs are marked by the red arrows. Scale bars: 500 nm.